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THE INSTITUTE OF PETROLEUM.

AN Ordinary General Meeting of the Institute of Petroleum was held at Manson House, 26 Portland Place, London, W.1, on April 12, 1950, with the President, Mr E. A. Evans, M.I.Mech.E., F.R.I.C., in the Chair.

The Minutes of the preceding Ordinary General Meeting, held on March 8, 1950, were read, confirmed, and signed.

THE GENERAL SECRETARY (D. A. Hough) announced the names of members elected since the preceding meeting and the Annual General Meeting on April 20, 1950.

THE PRESIDENT: We are to have a paper this evening by Mr L. D. Derry and Dr E. B. Evans.

Dr Evans is the Head of the Fuels Section of the Esso Development and Research Co. Ltd. Laboratories; he is a Vice-President of the Institute of Petroleum, and has been for a number of years our Associate Editor. Therefore, he is very well known, not only to members of the Institute, but also to a very wide audience over most of the world.

Mr Derry is in charge of the group dealing with diesel and burner fuels. He is an engineer who has had wide experience of diesel engines, and therefore is very well qualified to speak on the subject which the authors have chosen for this paper.

The following paper was presented by L. D. Derry:

COLD STARTING PERFORMANCE OF HIGH SPEED DIESEL ENGINES AND THEIR FUELS.

By L. D. DERRY (Assoc. Fellow) and E. B. EVANS (Fellow).

SUMMARY.

The relation of fuel properties to the starting performance of diesel engines has been investigated, consideration being given to results obtained on a single-cylinder experimental engine and on six commercially available multi-cylinder engines, of both direct- and indirect-injection types. A recording chronograph was developed for use in this work.

Cetane number is the most important single fuel property affecting starting performance, with volatility second in importance. In general, engine performance improves with increase in both these properties, but with some engines, design may be such that fuel characteristics generally have little effect. This is the case where compression temperatures are high due to high compression ratios, high motoring speeds, or to the addition of heat by auxiliary starting devices such as heater plugs. Where volatility is important, diesel index may give an excellent indication of the relative starting properties of fuels.

Some engines are relatively short of excess fuel for starting, and this may be aggravated by a governor design which cuts off excess fuel at idling speed, thus causing the engine to stall. In such cases higher fuel viscosity is beneficial, and may override the effect of volatility, which decreases as

viscosity increases. The effect is due to increased volumetric efficiency of the fuel pump with increased viscosity, and is more marked when the pump is worn.

At temperatures below the cloud point of the fuel, starting performance is poorer, due to partial blocking of the filter by wax crystals, than would be anticipated from a consideration of the cetane number and other properties of the fuel. This effect is more noticeable in cases where there is already a deficiency of excess fuel for starting.

Introduction.

The quick starting of diesel engines under all conditions of service is of particular importance if loss of valuable man hours is to be avoided. Although the English climate may be condemned in many respects, it does not normally provide unduly severe conditions for the starting of internal-combustion engines. Nevertheless, there are times when, on frosty days, it is necessary to resort to devices such as the application of blowlamps or burning rags soaked in oil to heat the air inlet to the engine in order to obtain a start. The problem of cold starting is of particular importance

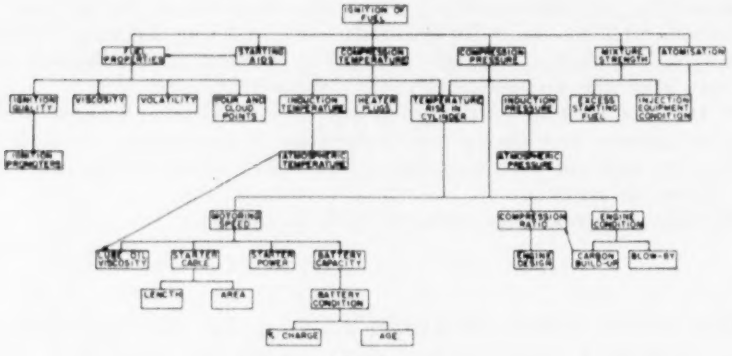

Fig. 1.

FACTORS AFFECTING THE COLD STARTING PERFORMANCE OF DIESEL ENGINES.

to manufacturers exporting their engines to countries where climatic conditions are more severe than in the U.K., and where the grades of fuel available may be quite different.

A recent study, using a number of different makes of engines to determine the effect of fuel characteristics on the starting performance of diesel engines, has indicated that not only do the starting performances of the individual makes of engines vary considerably, but also that their response to change of fuel characteristics varies widely. Considering the number of factors, shown in Fig. 1, which may affect the cold starting performance of diesel engines fitted with electric starting, it is hardly surprising that such differences do exist.

Many of the factors shown in Fig. 1, such as compression temperature and pressure, starter power, battery capacity, and lubricating oil recommendations, are essentially determined by the engine builder. Some of them may, however, be influenced by other factors under the control of the

operator, or by climatic conditions. For example, engine maintenance and battery condition, and to a limited extent choice of fuels and lubricating oils, are in the hands of the operator. Atmospheric conditions such as temperature and pressure are not subject to control, although the effect of the former may be moderated by the use of suitably heated storage.

Many of the factors are also interrelated, and where possible this has been shown by the connecting arrows in Fig. 1. For example, although atomization depends to a large extent on the design of the fuel injection equipment and conditions in the cylinder during injection, such as pressure and turbulence, it can be affected by the viscosity of the fuel.

The main object of this work was to determine the effect on cold starting of fuel properties such as ignition quality, volatility, viscosity, and cloud point under different atmospheric conditions.

Studies were made both in a single-cylinder, direct-injection engine and in six standard multi-cylinder automotive-type engines, the latter representing a variety of types of combustion systems. In the single-cylinder tests the procedure was designed to eliminate as many variables as possible so that the effect of fuel properties might be determined more rapidly, but in the multi-cylinder tests the procedure was designed to reproduce, as closely as possible, service conditions.

The use of a single-cylinder engine made it possible to test more quickly a wide variety of fuels, of which small quantities only were sometimes available. At the same time a number of factors, such as motoring speed, battery conditions, and compression pressure, could be kept constant, and variations of, for example, injection characteristics, between cylinders could be avoided. This enabled the effects of changes of fuel properties to be more readily examined, although these effects might in some cases be peculiar to the particular engine used and its conditions of operation.

In order to test the general applicability of results and conclusions obtained from work on the single-cylinder engine, it was felt necessary to examine the behaviour of fuels on a number of commercially available multi-cylinder engines, operated under conditions resembling more closely those obtaining in practice. This necessarily introduced a number of variables—differences between cylinders, battery condition, motoring speed, compression pressures, and temperatures—which are difficult or impossible to control, but it did enable the conclusions drawn from the single-cylinder engine to be examined for the general validity of their application to engine practice.

Test Equipment and Procedure.

The cold starting performance of a fuel in an engine can be expressed in two ways; either as the minimum temperature at which a start can be obtained in a given time, or as the time required to start at a given temperature. The single-cylinder test procedure was designed to give results expressed on the former basis, whereas that employed in multi-cylinder tests was such that either type of result could be obtained. Brief details of the two test procedures are given below, and more complete details in Appendix I.

(a) *Single-cylinder Test Procedure.*

The single-cylinder engine used was a standard direct-injection unit, similar in all respects to those used in general service, and having a bore and stroke of $4\frac{1}{4} \times 6$ in, and a compression ratio of 13 : 1. The engine was installed in a small temperature-controlled room, and after stable conditions had been obtained the engine was motored to a speed of 160 r.p.m., at which speed the starter motor was cut out and fuel injected into the engine. The minimum temperature at which a start could be obtained under such conditions was determined for each of the fuels tested.

(b) *Multi-cylinder Test Procedure.*

The multi-cylinder engines used were all standard automotive-type engines of both U.K. and other European manufacture. All engines were of the four-stroke type, three being direct-injection, and three indirect-injection units. The range of salient details covered by these engines are given in Table I.

TABLE I.

	Min.	Max.
Cylinder bore, in	3·5	5·0
Piston stroke, in	4·0	6·7
Capacity, litres/cyl	0·67	2·10
No. of cylinders	4	6
Compression ratio (nominal)	15 : 1	19 : 1
Max rated speed, r.p.m.	1,600	2,200
Starter-battery voltage	12	24
Starter-battery capacity, amp hr	110	185

In order to simulate service conditions, the battery as well as the engine, was installed in the cold room, and the maker's general operating recommendations followed as closely as possible. The starting procedure consisted of motoring the engine, with the throttle fully open, until a start was obtained or the motoring speed dropped appreciably. In the case of indirect-injection engines fitted with heater plugs in the cylinders, the heaters were switched on for 20 secs prior to motoring the engine.

The use of a chronograph, which enabled the variations of starting current to be photographed on a time base, greatly facilitated the observations of starting behaviour. A complete description of the equipment is given in Appendix II. The use of this apparatus not only tended to eliminate the human error factor, but also provided a permanent starting record which could be studied at leisure. In many cases this record provided valuable data on starting characteristics that would otherwise have passed unnoticed. Fig. 2 shows a typical starting record and gives a clear automatic indication of the times to "first fire" and "starter disengagement." The "motoring speed" can be calculated from the record. A full definition of the various terms used is given in Appendix III.

The criteria of starting performance selected for these studies was the time from engagement to disengagement of the starter motor, and this is referred to as "cranking time." This measure of starting performance was

selected for a number of reasons. The point of first fire was somewhat erratic, and the accurate assessment of this first point on the starting record at which the starting current dropped to zero was, on occasions, a matter of judgment. Furthermore, it was found that the time to first fire did not necessarily present in all cases a true indication of the relative starting performances of either different fuels in an engine or of different engines on a fuel. For example, is some engines the time between first fire and starter disengagement was very short, and in other engines relatively long. The point of starter disengagement, however, indicates the point at which all cylinders are firing and developing sufficient power to turn the engine without assistance from the starter motor. It is also a measure of the

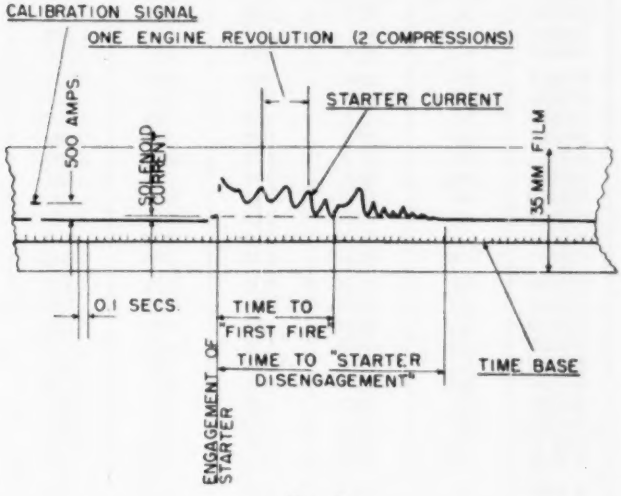

FIG. 2.

TYPICAL COLD STARTING RECORD FOR FOUR-CYLINDER, FOUR-STROKE ENGINE.

current drain from the battery, the capacity of which is one of the limiting factors in starting at low temperatures.

In each engine the starting performance of a number of fuels of different ignition quality was determined over a range of temperature. The effect of other fuel variables was then investigated on a number of additional fuels at a constant temperature. From the results of these tests the starting performance of a fuel could be expressed either as the time required to start the engine at a given temperature or, in some cases, as the minimum temperature at which a start could be obtained in a given time.

(c) *Fuels.*

Altogether seventy-six test fuels were used in this investigation. Salient details of those used in the single-cylinder tests are given in Table II and of those used in the multi-cylinder tests in Table III. The fuels in Table II are classified into two groups. Those described as " Normal diesel fuels " consisted of conventional fuels, from a wide variety of crudes, as marketed

TABLE II.

Fuel Inspection Data.

(Single-cylinder engine tests.)

Fuel No.	Sp. gr. 60/60° F.	Cetane No.	Diesel index.	Distillation, ° C.			Visc, cs at 100° F.
				10% at.	50% at.	90% at.	
			Normal diesel fuels.				
1	0·8794	36	39·5	240	285	360	4·5
2	0·8514	39	50·1	223	254	302	2·8
3	0·8358	52	60	238	266	296	2·9
4	0·8597	46	51	216	293	360	4·0
5	0·8443	54·5	59·4	242	286	334	—
6	0·8423	56·5	59·2	244	279	329	3·5
7	0·8227	62	72	240	292	333	3·6
8	0·9123	30	27·7	240	295	—	7·0
9	0·8591	42·5	49	218	267	336	3·4
10	0·8612	44	47·4	230	263	315	3·2
11	0·8473	57	59·5	240	281	340	3·9
12	0·8468	56	60	241	291	347	4·0
13	0·8423	54	63·3	256	282	322	4·0
14	0·8368	47	60·8	225	256	322	3·0
15	0·8571	41	49·2	216	269	328	3·4
16	0·8418	54·5	63·4	251	289	324	4·1
17	0·8413	58	62·2	243	288	331	3·8
18	0·8591	62	60·6	275	338	—	7·8
19	0·8100	53	65·8	194	223	256	1·7
20	0·8100	70·5	83·4	255	273	306	3·3
21	0·7896	62	81·2	203	218	254	1·6
22	0·8403	54	65·7	245	283	333	4·4
23	0·8468	55·5	63·9	265	301	356	5·6
24	0·8433	55·5	64·6	253	292	353	4·9
25	0·8203	51·5	68·9	214	240	282	2·4
26	0·8560	46·5	51	225	273	344	1·7
27	0·8309	57	70·2	230	278	347	3·8
28	0·8408	57	52·6	222	287	357	3·6
33	0·8612	43·5	48·9	225	273	332	3·3
34	0·9065	34·5	30·6	242	298	381	6·3
35	0·8463	58	59·3	246	290	345	4·1
36	0·8458	58	56·9	245	277	316	3·3
37	0·9212	31	29·5	241	304	—	13·4
38	0·8571	56	54·3	237	301	355	4·4
39	0·8871	44	36	234	294	355	4·3
40	0·8597	59	59·5	274	337	390	7·8
60	0·8413	57	66·3	255	294	355	5·1
			Narrow boiling cuts.				
41	0·7783	55	79·5	185	202	225	1·3
42	0·8100	65	74·3	246	261	288	2·6
43	0·8336	66	72	294	312	334	5·1
44	0·8478	44·5	52·2	244	258	281	2·7
45	0·8751	47·5	47·5	288	302	329	6·2
46	0·8978	47	42·9	346	355	372	16·9
47	0·8319	55	60·8	223	257	298	2·6
48	0·8493	45	49·8	208	242	281	2·4
49	0·8681	51	51·7	286	302	340	6·0
50	0·8328	38	54·6	185	218	284	1·7
51	0·8473	40	50·6	219	248	294	2·6
52	0·8800	44	47·3	292	320	367	9·0
53	0·8363	51	62·2	241	260	294	3·0
54	0·8493	57·5	64·3	289	308	338	6·2
55	0·8550	37·5	43	208	242	286	2·3
56	0·8778	39	39·2	250	278	318	4·0
57	0·9123	42	35·2	323	342	381	16·9
58	0·8072	70·5	82·3	248	263	289	3·0
59	0·8189	74	82·4	281	295	331	4·7

for various types of diesel engines. To determine the effect of fuel volatility on starting performance, nineteen "narrow boiling cuts," numbers 41 to 59 inclusive, were obtained from eight of the normal diesel fuels. Each cut had a boiling range of approximately 55° C (100° F), the boiling points of the cuts being nominally 177° to 232° C (350° to 450° F), 232° to 288° C (450° to 550° F), 288° to 343° C (550 to 650° F), and 343° to 399° C (650° to 750° F).

TABLE III.

Fuel Inspection Data.

(Multi-cylinder engine tests.)

Fuel No.	Sp. gr. 60/60° F.	Cetane No.	Diesel index.	Distillation, ° C.			Visc, cs at 100° F.
				10% at	50% at	90% at	
101	0·8418	50·5	60	218	268	339	3·3
102	0·8324	56·5	65	228	270	330	3·3
103	0·8546	48·5	53	227	285	335	3·8
104	0·8411	55·5	61	236	281	327	3·6
105	0·8610	40	48	223	276	316	3·5
106	0·8272	52	60	190	246	305	2·2
107	0·8426	52·5	56·5	230	264	307	3·0
108	0·8495	47	48	216	252	304	2·5
109	0·8655	39·5	43·5	217	258	330	3·2
110	0·8103	69·5	81	257	272	300	3·3
111	0·8403	60	60·5	246	282	337	3·7
112	0·8124	54·5	65·5	194	230	267	1·8
114	0·8498	54·5	55	247	281	320	3·6
115	0·8230	39	52	165	209	255	1·4
116	0·8394	49	58	200	263	326	2·8
119	0·7788	82	92	211	247	293	2·2
122	0·8610	45	51	234	290	345	4·3
128	0·8450	51	59	221	279	361	3·9
137	0·8386	56	58	248	280	346	4·1
140	0·9045	29·5	31·4	216	291	78·5% at 350° C	6·2

The fuels used in the multi-cylinder-engine tests also covered a much wider range of properties than is usual for fuels used in high-speed diesel engines. They ranged from kerosine to marine diesel fuel, and were derived from a variety of sources. The cetane numbers range from 29·5 to 82.

EFFECT OF FUEL CHARACTERISTICS.

Figs. 3, 4, and 5 present the results obtained in the single-cylinder engine, where the minimum starting temperature of each of the various fuels has been plotted against ignition quality. In Fig. 3 the results for all the fuels tested in this engine are shown against cetane number, the commonly accepted measure of ignition quality. The variation of the minimum starting temperature for fuels of equal cetane number is considerably greater than might have been expected, and consequently a further plot was made (Fig. 4) using diesel index as the measure of ignition quality. In this case the scatter of the points from the best line is considerably less.

The narrow-boiling cuts were prepared and tested expressly for the purpose of determining the effect of volatility on starting performance. Fig. 5 shows the results obtained both on the narrow cuts and on the fuels from which they were derived. Cuts from the same base fuels are connected together by dashed lines, and the fuel from which the cuts were made is indicated by a bracketed number near to the most volatile cut in the series.

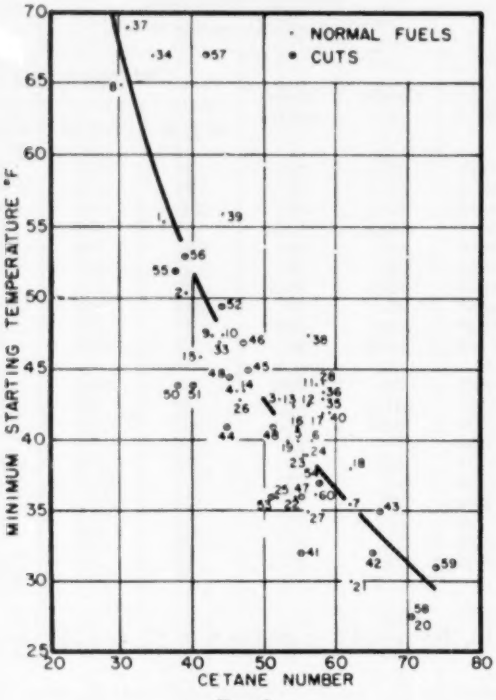

FIG. 3.

MINIMUM STARTING TEMPERATURE AND CETANE NUMBER (SINGLE-CYLINDER ENGINE).

Fuels of equal volatility are connected by full curved lines. The curve for the 288° to 343° C cuts is practically identical with that given in Fig. 3 for the whole range for fuels, and also for the fuels from which the cuts were made.

Figs. 6, 7, 8, 9, and 10 show typical results obtained in the multi-cylinder engines. Fig. 6 shows typical starting performance curves for fuels of different cetane number over a range of temperature in engine A, a direct-injection unit. At the lower temperatures starting becomes more difficult, particularly on the fuels of lower cetane number as shown by the curves becoming asymptotic to the *Y* axis. Similar curves to these were also obtained in engines B and C, direct- and indirect-injection units respectively.

Fig. 7 shows the starting performance at 20° F, in engines A and B, of a number of fuels of widely varying characteristics plotted against their cetane number. Similar results are obtained if the minimum starting temperature is plotted against cetane number as indicated in Fig. 8 for engine A, and it will be seen that this is very similar to Fig. 7.

Fig. 9 shows cold starting performance at 20° F plotted against diesel

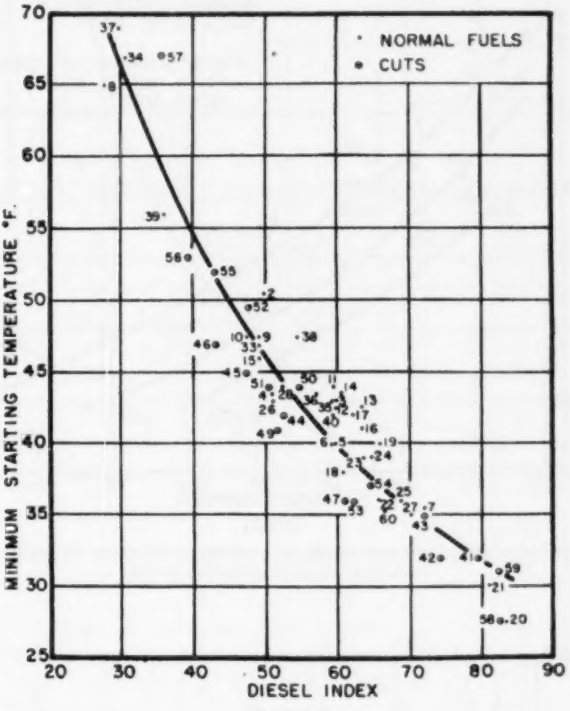

FIG. 4.

STARTING TEMPERATURE AND DIESEL INDEX (SINGLE-CYLINDER ENGINE).

index, and, in general, the correlation would appear to be about the same in these two engines with either cetane number or diesel index.

Fig. 10 shows the effect of cetane number on the starting performance at 20° F of the six engines tested; similar results are obtained if plotted on a diesel index basis.

(a) *Ignition Quality.*

In general, ignition quality as measured by either cetane number or diesel index would appear to be the most important single fuel characteristic affecting cold starting performance; the latter being expressed either as the minimum temperature at which a start can be obtained in a given time, or as the time required to obtain a start at a given temperature. There

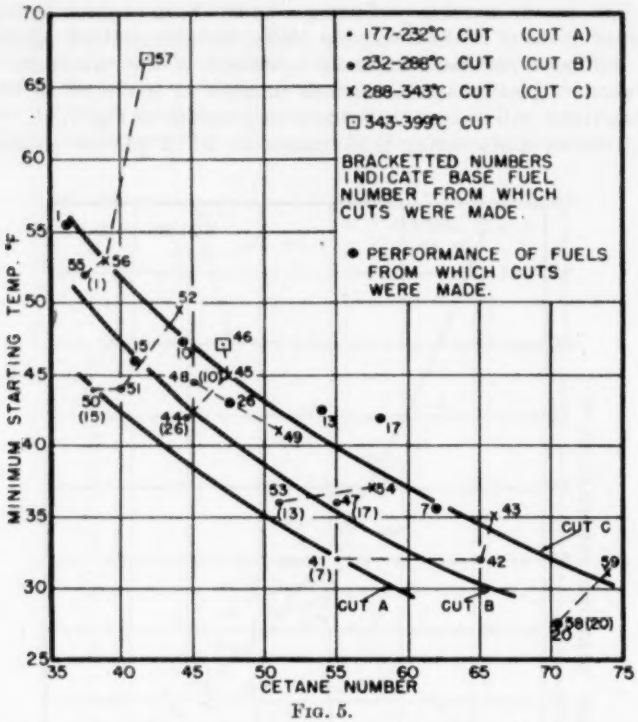
• 177-232°C CUT (CUT A)
• 232-288°C CUT (CUT B)
x 288-343°C CUT (CUT C)
⊡ 343-399°C CUT
BRACKETTED NUMBERS INDICATE BASE FUEL NUMBER FROM WHICH CUTS WERE MADE.
● PERFORMANCE OF FUELS FROM WHICH CUTS WERE MADE.
MINIMUM STARTING TEMP. °F
CETANE NUMBER
CUT A
CUT B
CUT C

FIG. 5.

MINIMUM STARTING TEMPERATURE AND CETANE NUMBER (SINGLE-CYLINDER ENGINE, NARROW BOILING CUTS).

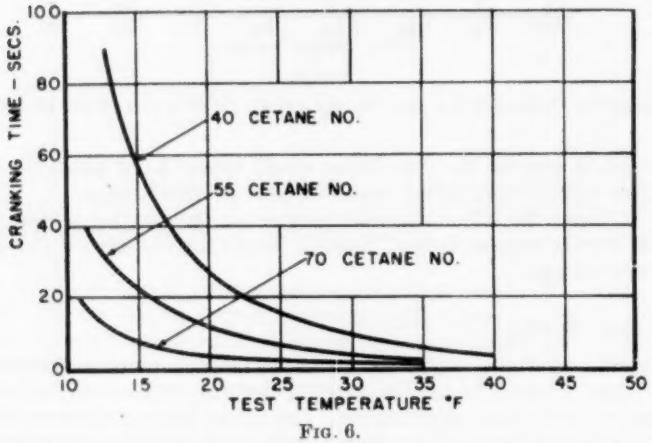

FIG. 6.

EFFECT OF CETANE NUMBER ON STARTING PERFORMANCE AT VARIOUS TEMPERATURES (ENGINE A).

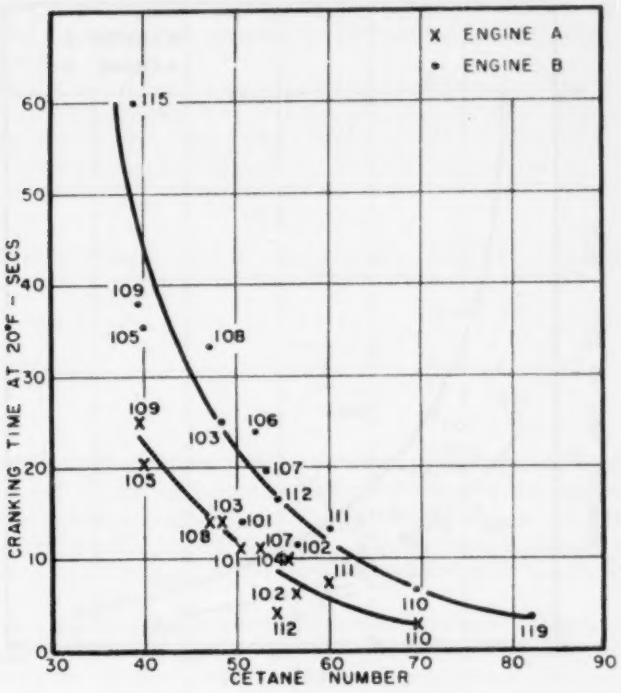

FIG. 7.

EFFECT OF CETANE NUMBER ON STARTING PERFORMANCE AT 20° F. (ENGINES A AND B).

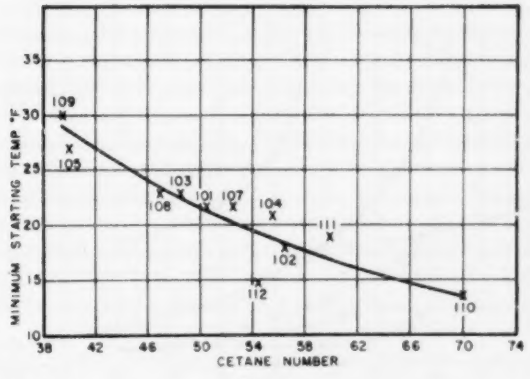

FIG. 8.

EFFECT OF CETANE NUMBER ON MINIMUM STARTING TEMPERATURE FOR START IN 10 SEC. (ENGINE A).

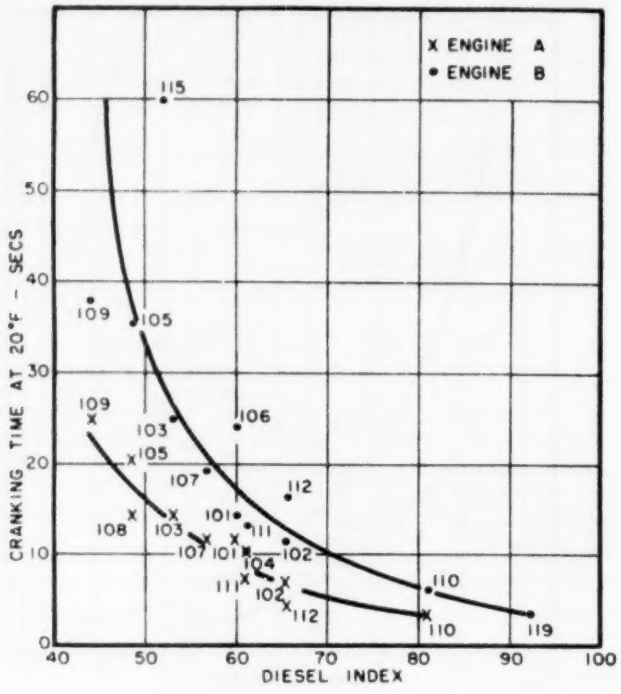

FIG. 9.

EFFECT OF DIESEL INDEX ON STARTING PERFORMANCE AT 20° F. (ENGINES A AND B).

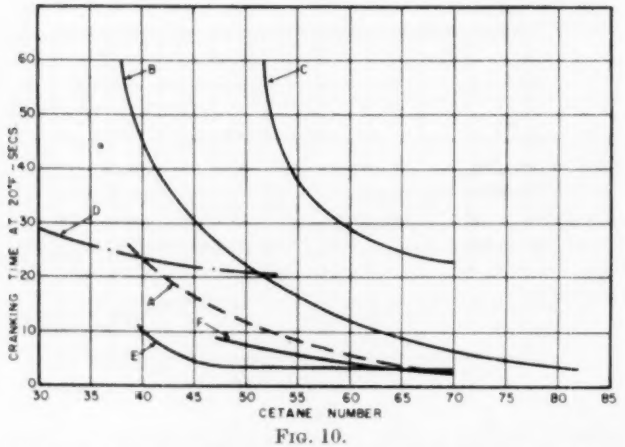

FIG. 10.

COMPARATIVE EFFECT OF CETANE NUMBER ON THE STARTING PERFORMANCE OF SIX MULTI-CYLINDER ENGINES.

are, however, engines available, the design of which is such that cold starting performance is not materially affected by a wide range of fuel characteristics.

From Figs. 3 and 4, which show results from the single-cylinder engine, it is seen that the correlation of starting performance with diesel index is appreciably better than that with cetane number. This is indicated clearly by results, given in Table IV, of a statistical analysis.

TABLE IV.

Variation of Minimum Cold Starting Temperature from Correlation Curve. Percentage within Indicated Brackets.

Independent variable.	±2° F.	±4° F.	±8° F.
Cetane No. . . .	32	59	90
Diesel index . . .	53	86	99

These results indicate that only 32 per cent of the experimental results fall within ±2° F (the estimated experimental error in the determination of minimum starting temperature) of the curve in Fig. 3 correlating the results as a whole with cetane number. On the other hand, 53 per cent would fall within the same limits when correlated with the diesel index curve shown in Fig. 4.

There are a number of possible explanations of why diesel index appears to be a better measure of engine startability than cetane number. Experimental error in determining minimum starting temperature will be the same in both cases (±2° F). For the determination of cetane number by the conventional methods, the specified limits of repeatability are ±2 cetane numbers [1] and the limits of reproducibility, which, although they have not been generally accepted, are undoubtedly of the same order. On the other hand, the diesel index, being calculated from the A.P.I. gravity and the aniline point, should be correct to within ±0·5 units. As one cetane number is approximately equal to one unit of diesel index, and assuming that both of them correlate with cold starting performance, the possibility of the larger potential errors in cetane number measurement would therefore detract from its usefulness as a measure of cold starting performance. This might account, at least in part, for the better agreement in the single-cylinder engine between cold starting performance and diesel index, than that obtained using cetane number.

Considering, however, the results obtained in the multi-cylinder engines A and B, Figs. 7 and 9, there would appear to be, in general, little to choose between cetane number and diesel index for correlation purposes. This difference in results between the single-cylinder and multi-cylinder engines may possibly be attributable to the smaller number of fuels tested in the latter case, or to other overriding engine or fuel effects. It is noteworthy, however, that certain types of engines, for example, D, E, and F (Fig. 10), have starting characteristics that are substantially independent of ignition quality, provided that the cetane number or diesel index of the fuel is above a certain, quite low, minimum figure. The reason for some of these effects will be discussed more fully later.

(b) *Volatility and Viscosity.*

Even in the cases where cetane number appears to be the most important fuel characteristic affecting cold starting performance, it is obvious from the results given previously that the variations observed cannot be associated entirely with experimental errors, and that other fuel factors must be exerting some influence.

The delay period between the start of fuel injection and inflammation of the mixture is usually regarded as being attributable to both physical and chemical causes. The physical delay is due to the time taken to achieve sufficient vaporization of the fuel and mixing this vapour with the necessary oxygen. The chemical delay, that is the time taken for the oxidation reactions to become sufficiently rapid for inflammation to ensue, depends primarily on the chemical constitution of the fuel.

Of the fuel properties affecting the physical portion of the delay period, volatility would appear to be the most important. The actual amount of vaporization will depend also on a number of other factors such as injection characteristics, including degree of atomization, penetration, etc., and compression pressure and temperature, and air turbulence. For fuels tested in the same engine, however, most of these latter factors will be reasonably constant, although atomization characteristics and the quantity of fuel injected may be affected, to some extent, by the viscosity of fuel.

The conventional measure of ignition delay is cetane number, which is usually determined in an engine under normal running conditions, in which case the compression temperature will certainly be not less than 600° C. At this temperature an appreciable proportion of any atomized conventional diesel fuel will readily vaporize, so that for most fuels the volatility might be expected to have relatively little effect on the cetane number determined under such conditions. Assuming that volatility is the most important fuel characteristic affecting the physical delay period, and that mechanical features are constant, then cetane number becomes primarily a measure of the chemical nature of the fuel. When starting a diesel engine under low ambient temperature conditions, these, together with the relatively low motoring speed and high heat loss, leakage of air past the piston rings, absence of hot residual gas, etc., combine to reduce the compression temperature by several hundred degrees. Under these conditions the increased importance of fuel volatility will be apparent.

The significance of the fuel volatility effect under cold starting conditions will be seen by consideration of the results obtained in the single-cylinder experimental engine on the narrow boiling range fuel cuts (Fig. 5). It will be seen from the three curves, each of which is drawn through the results on fuels of equal volatility, that maximum cold starting temperature is reduced markedly as the fuel volatility is increased. This holds for each of the individual series of cuts with one exception. It is therefore concluded that, in this engine, it is necessary to consider volatility in addition to cetane number when predicting the cold starting behaviour of fuels. The wide variation in fuel properties of the large number of fuels examined in this engine did not readily permit further direct comparisons of the effect of volatility, as such, to be made. The validity of the above conclusion has

therefore been examined by means of statistical analysis of all the data obtained in this engine.

Various measures of fuel volatility were considered, and their effect on cold starting performance compared graphically. As a result, multiple regressional analyses were made using 10 and 50 per cent distillation temperatures and the percentage distilled at 300° C as measures of volatility, and assuming a linear relationship between starting temperature and volatility. This resulted in an equation of the form :—

$$y = ax^2 + bx + cz + d$$

where y = minimum starting temperature;
x = cetane number;
z = volatility (10 or 50 per cent distillation temperature °C, or percentage distilled at 300° C);
a, b, c, and d = constants.

Table V indicates the comparative accuracy of minimum starting temperature prediction using cetane number alone and in combination with the measures of volatility considered.

TABLE V.

Variation of Minimum Cold Starting Temperature from Correlation Curve. Percentage within Indicated Brackets.

Independent variables.	±2° F.	±4° F.	±8° F.
Cetane No.	32	59	90
Cetane No. and 10% distillation temperature .	35	64	93
Cetane No. and 50% distillation temperature .	38	67	95
Cetane No. and % distilled at 300° C . .	39	69	96

These figures indicate that even if the best volatility correction is made, only 39 per cent of the experimental results fall within ±2° F of the values calculated from the independent variables using the equations obtained. A more exact analysis, involving volatility, leads to an equation of the form :—

$$y = ax^2 + bx + cxz + dz + e$$

where z = percentage distilled at 300° C and e = constant. Other symbols are as given previously.

The solution of this equation indicates that the effect of volatility on starting performance becomes progressively more important as the cetane number is reduced. An increase in volatility of from 0 to 100 per cent distilled at 300° C reduces the minimum starting temperature by 21° F at a 30 cetane number level, but by only 9° F at 60 cetane number. The effect of other fuel properties in combination with cetane number was investigated, but it was not possible to obtain as good a correlation as those previously given.

Before the introduction of cetane number, the empirical function known as diesel index $\left(\frac{\text{Aniline pt. °F} \times \text{° A.P.I. Gravity}}{100}\right)$ was proposed[2] as a

measure of ignition quality of diesel fuels. It is still often used, where engine test facilities are not available, and a correlation with cetane number has been worked out involving a volatility correction.

This correlation [3] is expressed by the equation :—

$$\text{Cetane No.} = 2/3 \text{ Diesel index} + 0{\cdot}068 \text{ M.B.P. } ^\circ\text{F} - 22$$

or $$\text{Cetane No.} = 2/3 \text{ Diesel index} - (22 - 0{\cdot}068 \text{ M.B.P. } ^\circ\text{F})$$

Thus for fuels of equal cetane number, the greater the volatility of the fuel the lower is the mid-boiling point and the greater is the numerical correction to be made to the diesel index. In other words, it appears that to obtain a correlation with cetane number, *i.e.*, with the chemical portion of ignition delay, it is necessary to remove from diesel index a factor which increases with the volatility of the fuel. It is not surprising therefore, that diesel index, although it does not directly correlate very accurately with cetane number which is determined under running conditions, does correlate quite well with cold starting performance. This is shown by the results of a statistical analysis, given in Table VI, which gives also similar results for cetane number alone and cetane number/volatility.

TABLE VI.

Variation of Minimum Cold Starting Temperature from Correlation Curve. Percentage within Indicated Brackets.

Independent variables.	±2° F.	±4° F.	±8° F.
Cetane No.	32	59	90
Cetane No. and % distilled at 300° C . .	39	69	96
Diesel index	53	86	99

The figures in the second line of Table VI are based on the simpler equation :—

$$y = ax^2 + bx + cz + d$$

which, although it does not represent the results quite so accurately as does the five-constant equation also developed, is sufficiently accurate for most purposes and more convenient to use.

The fact that a better correlation is obtained between minimum starting temperatures and diesel index than with cetane number, even after making an allowance for volatility, may be due to the greater error associated with the measurement of cetane number than that with the measurement of diesel index, as discussed previously.

In the multi-cylinder engine tests the effect of both ignition quality and fuel volatility on cold starting performance varied considerably in the different makes of engines. In certain cases it is possible to make direct comparisons of the starting performance to show the effect of fuel volatility as such, and Table VII shows these comparisons for engines A and B. In engine A an increase in fuel volatility appears, in general, to improve the cold starting performance, whereas in engine B the reverse is apparently the case. Consideration of the results as a whole in each of the engines by means of a statistical analysis, confirms these observations, although in neither

case is the effect of volatility so marked as in the particular examples previously considered.

TABLE VII.

Effect of Viscosity and Volatility on the Starting Performance of Fuels of "Equal" Cetane Number.

Fuel No.	Cetane No.	Visc, cs at 100° F.	Distillation, ° C.			Sp. gr. 60°/60° F.	Cranking time at 20° F, sec.	
			10% at	50% at	90% at		Engine A.	Engine B.
104	55·5	3·6	236	281	327	0·841	10	10
102	56·5	3·3	228	270	330	0·832	6	11
112	54·5	1·8	194	230	267	0·812	4	17
105	40	3·5	223	276	316	0·861	20	35
109	39·5	3·2	217	258	330	0·866	25	38
115	39	1·4	165	209	255	0·823	—	60

In the case of engine A a slightly better correlation is obtained with diesel index than with cetane number (Figs. 7 and 9), which is in agreement with the findings in the single-cylinder engine. In engine B, however, the reverse is the case. That this effect in engine B was really significant, and the reason for it, was not fully appreciated until similar results were obtained in another engine, E.

In engine E, ignition quality appeared to have little effect on the starting performance provided the cetane number was above about 47 as indicated by the curve for this engine in Fig. 10. At a temperature of 10° F a similar relationship was indicated, but considerable variations in starting performance were obtained with different fuels as shown by the Table VIII, which also contains relevant fuel-inspection data.

TABLE VIII.

Fuel No.	Cetane No.	10% dist pt, ° C.	50% dist pt, ° C.	Visc, cs at 100° F.	Cranking time, sec.
128	51	221	279	3·9	6
103	48·5	227	285	3·8	8
110	69·5	257	272	3·2	12
116	49	200	263	2·8	13
108	47	216	252	2·5	15
112	54·5	194	230	1·8	15

A good relationship was obtained by plotting starting times directly against the 50 per cent distillation temperatures. In this case, starting performance again deteriorated with increased fuel volatility. As there is an approximate correlation between the 50 per cent distillation temperature and fuel viscosity, the relationship of the latter to starting time was investigated. An excellent correlation was obtained, and it is concluded that in the case of this engine the main factor affecting starting times is fuel viscosity, independent of ignition quality. It is appreciated that fuel

viscosity has a fundamental influence on the injection characteristics of diesel engines and that this property affects, for example, droplet size and penetration. Such factors are of importance to the overall operation of the engine, but we are concerned here not with the basic questions of design but with the effects of variation of fuel characteristics on startability of the engine as delivered, or as it subsequently becomes in normal operation.

Motoring tests, with fuels of different viscosity, indicated that the volume of fuel delivered by the main fuel-pump increased with fuel viscosity. For example, a difference of 11 per cent by volume was obtained between fuels number 112 and 128. It is well known that the cold starting performance of diesel engines can be improved by increasing the fuel delivery during the starting period by up to as much as 100 per cent above that required for normal full load operation. Subsequent tests in this engine indicated that substantial improvements in starting performance could be obtained by increasing the quantity of excess starting fuel above that provided by the makers. The improvement in starting performance with the more viscous fuels can therefore be attributed to a greater quantity of fuel being delivered to the engine, and this can be associated with less fuel-pump leakage.

This increase in fuel-pump volumetric efficiency with the more viscous fuels also accounted for the similar results obtained in engine B. Further investigations on this engine showed that the fuel-pump condition was such that the volumetric efficiency was markedly affected by fuel viscosity.

In engine C insufficient fuels were tested to obtain data showing the effect of fuel volatility and viscosity, but it might be expected that this engine would be increasingly sensitive to fuel viscosity with a worn pump on account of the type of governor fitted.

In engine D the effect of the main engine fuel characteristics, both cetane number and volatility, were almost completely masked by the supply of a kerosine auxiliary starting fuel, which was ignited in the air-inlet manifold.

A limited number of tests were made to determine the effect of both the ignition quality and volatility of the auxiliary starting fuel on starting performance. Comparative test data are given in Table IX.

TABLE IX.

Test temp, ° F.	Auxiliary fuel.		Cranking time, sec.
	Cetane No.	50% dist pt, ° C.	
20	55	211	30
20	34	191	28
20	30	291	Would not start
30	30	291	42

These results indicate that the cetane number of the auxiliary fuel has no effect on cold starting performance, but that starting improves with increased fuel volatility. This can no doubt be associated with the more complete combustion of the volatile fuel in the air-inlet manifold. In engine F only a limited number of fuels was tested. The results indicate that, in this engine also, the effect of ignition quality on starting perform-

ance is small with fuels above about 47 cetane number. The effect of volatility, as such, was not investigated.

(c) *Cloud Point.*

The previous results have indicated that, in general, starting performance at low temperature improves with increase in the cetane number of the fuel, but that fuel volatility and viscosity may have important, and sometimes overriding effects. It is well known that the cloud points of fuels tend to increase with their cetane numbers, and at low temperatures might therefore be expected to affect the cold starting performance of the fuel. This is

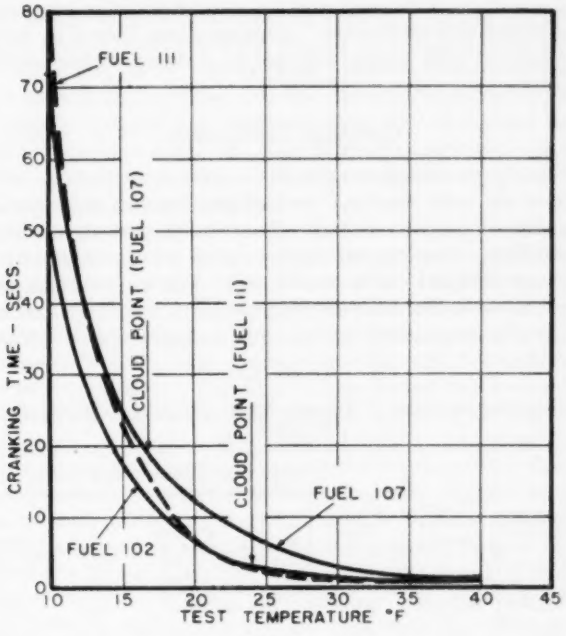

FIG. 11.

EFFECT OF CLOUD POINT ON STARTING PERFORMANCE.

illustrated in Fig. 11, where the starting performance of three fuels of varying cetane number and cloud point, but substantially equal volatility, is shown over a range of temperature. As indicated in Fig. 11 and Table X, the starting performance of fuel 111 is substantially the same as that of fuel 102 at temperatures above its cloud point, but deteriorates rapidly at lower temperatures, and eventually the starting performance becomes worse than that of fuel 107 which has a considerably lower cetane number. In the case of fuel 107 it is difficult to detect any deterioration in starting performance at temperatures below its cloud point, the only indication is that at 10° F the line is practically asymptotic to the *Y* axis, whereas this is not so apparent in the case of fuel 102.

TABLE X.

Fuel No.	Cetane No.	Cloud pt, ° F.	Pour pt, ° F.	Cranking time secs at :		
				30° F.	15° F.	10° F.
111	60	24	15	1	23	80
107	52·5	16	5	3	25	70
102	56·5	10	−5	1	18	50

The influence of cloud point on starting performance is much more marked with some fuels than others, and for a given set of conditions will depend on the nature of the wax and the rate at which it separates from the fuel with reduction of temperature. In some cases, therefore, full advantage cannot be taken of high cetane number in starting at temperatures below the cloud point.

GENERAL DISCUSSION.

The previously presented results have indicated that the effect of fuel characteristics on cold starting performance varies considerably in the different makes of engines tested. They have also shown that ignition quality, volatility, viscosity, and cloud point are the most important fuel characteristics which have to be considered. The wide variations in starting performance between the different engines, with respect to fuel characteristics, must then be associated with engine design features. Table XI lists

TABLE XI.

Relative Starting Characteristics of Various Types of Diesel Engine in Relation to Fuel Properties.

Engine.	Combustion system.	Relative motoring speed.	Starting aids.	Relative engine-starting characteristics.		Cold starting performance improves with increased fuel.		
				Time to 1st fire.	Time, 1st fire to starter disengt.	Cetane No.	Volatility (50% dist point).	Visc.
Single cylinder	D.I.*	Very high	None	Not recorded		Yes	Yes	No
A	D.I.	High	None	Variable	Short	Yes	Only slightly	No
F	D.I.	Very high	None	Constant	Short	Only slightly	Not investigated	
B	D.I.	High	None	Variable	Long	Yes	No	Yes
D	I.I.†	Low	Auxiliary fuel burnt in air inlet	Constant	Short	Only slightly	No	No
C	I.I.	Medium	Cylinder heater plugs	Variable	Long	Yes	Not investigated	
E	I.I.	Medium	Cylinder heater plugs	Constant	Long	No ‡	No	Yes

* D.I. indicates direct injection.
† I.I. indicates indirect injection.
‡ Above about 47 cetane number.

salient details of the engines and their starting characteristics with relation to fuel properties; the engines in each class of direct and indirect injection being arranged in order of increasing compression ratio. For the present, the effect of cloud point will not be discussed.

Of the four direct-injection engines, the single-cylinder unit has a relatively low compression ratio and therefore low compression pressure and temperature. As would be expected under these conditions cold starting performance improves with both increase of fuel ignition quality and volatility. Under these conditions diesel index, which appears to contain a volatility factor not inherent in cetane number, gives the best correlation with minimum starting temperature. The effect of fuel volatility is most marked when comparing cuts from the same base stock. When considering, however, the effect of volatility of fuels from different base stocks, direct comparisons are not always entirely consistent, but there is a general trend indicating the effect of volatility. Comparing engines A and B with the single-cylinder unit, it is seen that ignition quality is important in all three cases, but whereas volatility also is important in the single-cylinder engine, it is less so in engine A, and has no apparent effect on the starting of engine B. As engines A and B have compression ratios some three numbers higher than has the single-cylinder unit, with correspondingly higher compression temperatures, the decreased influence of volatility would be expected. Engine B shows, however, an interesting effect, in that increased viscosity (corresponding to decreased volatility) has a beneficial effect on cold starting.

With fuels of lower viscosity the volumetric efficiency of the fuel-pump is reduced, that is, less fuel is delivered per pump stroke, and this effect will become more apparent with progressive wear of the injection equipment. The effect of fuel viscosity in engine B can be associated with the relatively high fuel leakage due to pump wear. In such circumstances the beneficial effect of increased fuel viscosity overshadows the slight deterimental effect due to decreased volatility. This effect of increased fuel viscosity masking that of fuel volatility can lead to difficulties in selecting the correct grade of fuel. For example, an engine when tested initially may show a preference for a volatile fuel for cold starting, but after being in service for some time may then show a preference for a less volatile, more viscous fuel.

The starting performance of engine F is only slightly dependent on the ignition quality of the fuel, although the compression ratio is intermediate between those of engines A and B. The motoring speed of this engine is, however, particularly high, and so therefore in consequence are the compression pressure and temperature. Although the effect of volatility and viscosity were not systematically investigated for this engine, it would not be expected that either of these would be important.

All the indirect-injection engines are fitted with auxiliary devices for heating the air charge, either before or in the cylinders, and where these are adequate (engines D and E) the effects of fuel ignition quality and volatility are not important. The compression ratio of engine D is considerably lower than of engines C and E, and it is therefore not unexpected that ignition quality has some slight influence on starting performance. Volatility appears to be the most important fuel characteristic of the auxiliary fuel; starting performance improving with increased volatility. It is probable that all of the auxiliary starting fuel is not burnt in the air-inlet manifold, and the presence of this unburnt fuel, probably in vapour phase, in the engine cylinder, masks any volatility effect of the main engine fuel.

The starting of engine C is assisted by cylinder heating plugs, but ignition quality is still important. The long period between first fire and starter disengagement can be associated with the governor design. In this engine the excess starting fuel is cut off at idling speed. This sudden reduction in fuel quantity, just when the engine is beginning to accelerate, tends to cause the engine to stall, and the starter motor is called upon once more to assist in turning the engine. Insufficient work was carried out to determine whether volatility or viscosity was the more important subsidiary property. It is known, however, that modifying the governor and continuing the excess starting fuel for a longer period, improves the starting performance.

The excellent starting performance of engine E, and its insensitivity to ignition quality and volatility can be attributed to the relatively large heater plugs employed. On the other hand, cold starting improves with increased fuel viscosity, indicating that there is a deficiency in the quantity of fuel delivered to the cylinders. The greater volume of fuel delivered per stroke with the more viscous fuels tends to overcome this deficiency. The long period between first fire and starter disengagement is consistent with these conclusions.

It was shown previously that when starting at temperatures below the cloud point of the fuel, the starting performance was poorer than would be expected from the ignition quality and volatility of the fuel. This was due to partial blocking of the fuel filter by wax crystals, thus reducing the supply of fuel to the engine. This effect would apply to all engines, though in varying degrees. For example, the engines which would be first affected are those which are already deficient in fuel.

Conclusions.

Examination of the cold starting performance of a large number of diesel fuels of widely varying characteristics in a number of standard, commercially available, high-speed diesel engines indicates that cetane number, volatility, viscosity, and cloud point are the most important fuel properties. In general, cetane number would appear to be the most important single property; starting performance improving with increase in cetane number. In all cases both increased volatility and increased viscosity tend to improve starting performance, but the relative importance of these two factors varies greatly between different makes of engines. From the way in which the physical properties of hydrocarbon fuels are related, increased viscosity must be associated with reduced mean volatility, and in cases where, at first sight, better starting appears to be associated with reduced volatility, it is in fact the effect of increased viscosity which is responsible for the improvement. The design of engines may, however, be such that fuel characteristics have no significant effect on cold starting performance. Although starting can be obtained at temperatures below the cloud point of a fuel, the performance is usually poorer than would be expected from the cetane number and volatility of the fuel. Detailed examination of the results has enabled the following conclusions to be drawn.

Cold starting performance improves with increased cetane number, and

increased fuel volatility, as such, is also beneficial in engines where the compression pressure and temperature are low, either due to low compression ratio and/or low motoring speed. The effect of increased fuel volatility becomes more important as the cetane number of the fuel is reduced. As the compression pressure and temperature are raised, first the effect of fuel volatility is eliminated and finally that of cetane number.

Diesel index may be the best measure of starting performance in engines where cold starting improves significantly with fuel volatility. A consideration of the nature of ignition delay and the methods of measuring cetane number indicates that the effect of fuel volatility on ignition delay is masked by the high-temperature conditions under which the cetane number measurement is made. It is known that for fuels of equal cetane number the diesel index increases with fuel volatility, and this undoubtedly accounts for the better correlation, under these conditions, with diesel index. Nevertheless, it would not be recommended that diesel index should generally replace cetane number as a measure of the starting performance of fuels, as the effect of volatility may be largely eliminated by the use of high compression ratios or high motoring speeds, or by the employment of auxiliary heating devices. These conditions do, at the same time, make cetane number also of lesser importance to starting.

In some cases cold starting performance improves with increased fuel viscosity (decreased volatility). This occurs in engines where the fuel-pump leakage increases significantly with reduction of viscosity and where there may be a deficiency in the quantity of fuel delivered to the engine during starting. This may be due to insufficient excess fuel, on account either of the excess fuel stop setting, or of the design of the governor. This improvement in starting performance with the more viscous fuels can be associated with an increase in the fuel-pump volumetric efficiency. A deficiency in fuel supply is characterized by a long period between first fire and started disengagement.

Neither cetane number nor fuel volatility are of importance where the compression pressure and temperature are sufficiently high, either on account of adequate supplementary air heating or of high motoring speed.

Where the auxiliary fuel is burnt in the air-inlet manifold the volatility of the auxiliary fuel would appear to be the most important fuel characteristic, starting performance improving with increased volatility. In such cases the effect of the main engine fuel characteristics on cold starting may be completely masked.

The effect of cetane number and volatility on starting performance can be eliminated in the case of indirect-injection engines by the provision of sufficiently large heater elements in the cylinders.

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APPENDIX I.

Cold Starting Test Procedure.

General.

The engine was installed in a cold room in which the temperature of the air was automatically controlled. The room was cooled down until the desired test temperature was reached, and the engine allowed to soak, at that temperature, until the engine coolant and the lubricating oil in the sump were also at the test temperature. To ensure that temperature conditions were absolutely uniform a further short soaking period was allowed even after the coolant and lubricating oil were down to temperature. The lubricating oil temperature was recorded against time to ensure that conditions were stable. The air, coolant, and lubricating oil temperatures were measured finally by thermocouples connected to a potentiometer.

After each test the engine was operated at a speed of 1000–1200 r.p.m. until the engine coolant reached a minimum temperature of 120° F. This period of operation was to ensure that no accumulated fuel was left in the cylinders, and to renew the film of lubricating oil on the cylinder walls.

If the engine failed to start in any particular test, it was forced to start, usually by raising the air temperature, and then operated as described in the previous paragraph before proceeding with the next test.

As a check on engine performance one fuel was taken as a reference and checked periodically.

Single-cylinder Engine Test Procedure.

When the desired test conditions had been obtained the engine was motored with the decompressor valve open and the fuel-pump rack at zero delivery until a speed of 160 r.p.m. was attained. At this speed the starter switch was released, and simultaneously the decompressor valve closed and the fuel-pump rack moved to normal maximum delivery. The minimum temperature at which the engine could be started, using this procedure, was recorded.

Multi-cylinder Engines.

The engine and three sets of the recommended size of starting battery were installed in the cold room. The diameter and length of starter cable were the same as that used in service with the particular make of engine being tested. Each set of batteries was used in turn, and prior to use the specific gravity of the battery acid was checked, due allowance being made for temperature. All tests presented were made with fully charged batteries.

The grade of lubricating oil used was in accordance with the engine manufacturer's recommendations for the test temperature. The oil was changed when the dilution, as indicated by change of viscosity, reached 0·5 per cent. Before the oil was changed the engine was operated until the lubricating oil temperature in the sump reached 120° F. In all cases the throttle was fully open, and in engines where excess fuel was available for starting this was used.

In the case of direct-injection engines without starting aids, the engine was motored until it started or the battery was becoming exhausted, as indicated by a drop in motoring speed.

In the case of indirect-injection engines fitted with heater plugs in the cylinder, the heater was switched on for 20 sec prior to motoring the engine. The engine was then motored as in the case of the direct-injection engines. The period for which the heater element was switched on, prior to motoring the engine, was not included in the starting time.

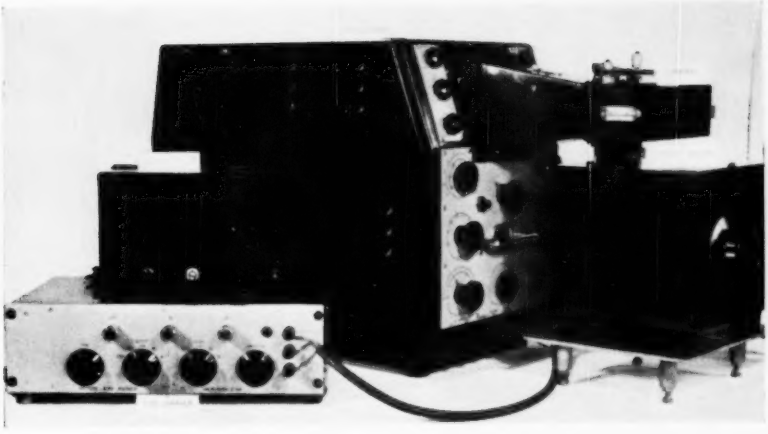

FIG. 12.

RECORDING CHRONOGRAPH.

[*To face p.* 412.

APPENDIX II.

Recording Chronograph.

To reduce experimental error to a minimum, a recording chronograph was designed to obtain a complete record of the starting process. This instrument recorded photographically the variations of engine starting current on a time basis.

A small standard resistance was inserted in series with one of the main battery to starter motor leads, and the voltage drop across this resistance was taken, through a suitable D.C. amplifier, to one pair of plates of a double-beam oscillograph. A 10 c.p.s. time signal was connected to the second pair of plates. The excursions of the two spots on the cathode ray tube screen were recorded by a 35-mm continuous-film camera driven by a variable-speed motor. A photograph of the apparatus is shown in Fig. 12.

Calibration of the starting current record was effected by applying a standard signal of known strength through the D.C. amplifier to the current recording beam just before and immediately after the cold starting current record. From the photographic record obtained, a typical example of which is given in Fig. 2, the following data can be obtained : maximum and minimum starting current, engine speed, points of starter engagement, first fire, and starter disengagement. If desired, additional points such as steady running can be added by the operator by applying the standard signal at the appropriate time.

APPENDIX III.

Definition of Cold Starting Terms.

The following definitions apply to the terms used in the analysis of the results :—

Engagement of starter was the point at which the starting current commenced to rise rapidly, that is the point at which the pinion was fully engaged and commenced to turn the engine.

First fire was taken as the first point on the record at which the starting current dropped to " zero," indicating that sufficient power was being developed momentarily by combustion to turn the engine without help from the starter.

Disengagement of starter was the last point at which any current was taken by the starter motor, and was thus the point at which the starter button could be safely disengaged without stalling the engine.

Motoring speed r.p.m. was the speed calculated from the starting record. This was usually based on the time to complete the second engine revolution after the engagement of the starter. In most cases no firing occurred during this period.

Steady running was the point, recorded aurally, at which the engine ran steadily without misfiring.

No fire was used to denote that firing was either non-existent or not sufficiently powerful to reduce the starting current to zero.

Discussion.

Mr C. D. Brewer : Could the authors say what would be the influence on their conclusions, or whether their conclusions would be significantly different, if the temperatures at which they made their investigations had been very much lower than in fact they were? Generally speaking, these temperatures were of the order of 20° F. I suggest that if they had been at around −20° F other fuel characteristics would have become more significant.

I feel rather inclined to dispute the authors' conclusion that ignition quality is the predominant fuel characteristic influencing starting. From my reading of the paper it seems that it runs very nearly to a dead heat with other characteristics.

I think it is rather unfortunate that the authors have used artificial starting aids, for, particularly in the indirect injection engines, they would rather camouflage some of the influence of the fuels; I think Mr Derry

mentioned that one engine started as though the heater plug were of a higher rating. It would be interesting if the authors could give some information of the engine starting characteristics without the use of starting aids.

Then, I wonder why in the experiments the direct measurement of engine speed was not considered as giving an indication of starting. I appreciate that that can be derived from the data presented, but in view of the great importance of knowing the instantaneous turning speed throughout the cycle, I should have thought that its measurement would have been quite easy and a little more direct.

I am very puzzled about the authors' reference to the volatility of the auxiliary starting fluid. I would have thought that high volatility would have implied greater inflammability and, therefore, there would be less chance of volatility vapours, whatever they are, entering the engine. My own experience of burning an auxiliary fluid in the manifold is that it must heat the incoming air only without appreciably reducing its oxygen content. I do not therefore understand the implication of this statement, and I should be glad if the authors would give a little more information on this point.

S. J. W. PLEETH: In the section of the paper dealing with the effect of fuel characteristics, (*b*) volatility and viscosity, there is a table giving details of the work on engine E, where there appears to be a negative correlation between cranking time and viscosity at 100° F. Would it be more relevant to compare the cranking time and the viscosity at 20° F, because then there might be a completely different correlation?

J. G. WITHERS: I wonder whether the authors can throw any light on the reasons why over-fueling improves starting? There are several theories, one of which is that the increased quantity of fuel increases the injection pressure, which, in turn, results in finer atomization. The smaller droplets will have a higher surface/volume ratio, and their temperature will, therefore, rise more rapidly; the delay period will thus be reduced. It may well be that viscosity is the important factor affecting starting, rather than volatility. The higher the viscosity, the poorer the starting, under normal conditions on account of larger droplet size, unless the leakage factor, mentioned by the authors, is over-riding.

M. VULLIAMY: I am rather intimately connected with engines, so that my remarks will be made from the point of view of an engineer and may not appear to be connected closely with fuel.

First I would support whole-heartedly the procedure which the authors have adopted in the cold starting tests. So far as I know—and I have seen results from four or five laboratories dealing with cold starting tests—this is the only case in which engines are actually run to restore cylinder conditions between each distinct test. This is of great importance. I have seen reports of tests in which an engine is just put into a cold room and cranked. If it fires, so much the better. If it does not fire in reasonable time, the cranking continues; sometimes another fuel is put in, or the chamber temperature altered and the cranking starts again.

I hope that eventually there will be a standardized procedure for cold

starting tests; this is a matter in which one of the organizations connected with the industry might interest itself.

It is a little odd to an engineer connected with engines having a certain indirect ignition system that in this particular case all the direct injection engines dealt with have a very much higher cranking speed than have the indirect injection engines. We have heard that direct injection engines are better to start than are the indirect, and one wonders now whether that reputation is due partly to the use of much higher cranking speeds.

I think the usefulness of the paper to engineers would be increased if the order of cranking speed were given, not necessarily in detail. Perhaps the information could be given in the table of maxima and minima.

Again, in regard to Table IV, I think the facts would be made a little more clear if the authors would indicate, in the column headed "Starting Aids," which engines were fitted with excess fuel devices. Engine D might be regarded as having an excess fuel device in the form of its auxiliary intake injection.

I wonder also whether cylinder size was found to be of any importance, or whether it was generally bound up with compression ratio and cranking speed, because, after all, it is bound up with heat losses. There has been much talk about there being a limit to the smallness of diesel engine cylinder mainly from the point of view of starting.

Unfortunately, I have been able to recognize engine D, and I have heard on good authority a rather interesting point. If the heater is not used, but only the spray of auxiliary fuel, a slightly better start is obtained when using burning oil than when using vaporizing oil, assuming the volatilities of the two oils are similar. In recent times—since some of the work described in the paper was done—it has become common for engine D to use fuel oil in place of kerosine, merely for the sake of convenience, for it avoids the necessity of carrying a different supply of fuel. I understand that in practice no trouble has arisen as a result.

Engine E shows a very quick start when using fuels of above 45 cetane number; but in practice we are not very interested in fuels much above 45 cetane number. At below 45 the curve starts to turn up rather rapidly, and it would have been more interesting if the curve were extended farther downwards. It might then have crossed some of the other curves, particularly D, which was tested down to 29 or 30 cetane (Fig. 10).

There is the point that indirect injection engines are supposed to be more insensitive to fuel variations than are the direct injection type. But the fact that the curve E appears to turn up rather rapidly at the low cetane end appears to contradict that.

F. L. GARTON: Looking at the fuel inspection data in Tables I and II, I take it that all the fuels tested were normal fuels, or cuts from them, and did not contain any additives. I wonder whether the authors have made starting tests with fuels containing additives.

Further, have they any data on air cell engines? There are certain types which operate better on the lower cetane fuels than on the very high cetane fuels, but I am not aware of any information concerning their starting properties.

My last question is perhaps not directly related to cold starting, although

it bears on the data presented by the authors. Some years ago a diesel fuel was fractionated into a series of cuts and the cetane numbers determined. It was surprising to find that the cetane number of the full range fuel was appreciably higher than the weighted average cetane number of the cuts prepared from it. The difference was not very great, but was greater than the experimental error. I wonder whether the authors have found anything similar in connexion with the cuts they mentioned.

G. M. BARRETT: With regard to the effect of cloud point, the authors attribute it to the blocking effect of the wax on the filters. I wonder whether they have any idea of the magnitude of the effect of temperature on the flow from the fuel pump.

L. E. LOWE: I think the cranking speed of 160 r.p.m. is a good deal faster than the speed at which any commercial type of engine can be revolved at the starting temperature of 20° F. The practical operator would probably say, "Can you show me an engine which will turn at that speed at 20° F in service?" This fairly high turning speed favours the authors' starting results, and I wonder whether the fuels would behave in the same way and would give results of the same order at lower cranking speeds.

One would like to hear more on the effect of fuel viscosity on pump volumetric efficiency. Have the authors any figures for pump leakage in the viscosity range they quoted? That is a matter of interest to the user, particularly where the pumps are worn.

Have they made any attempts to correlate air movement with starting performance in the two types of engines they chose—the direct and the indirect injection types—because I think there are results available to show that air movement can have quite an important effect on the delay angle or delay period they have mentioned? Also it seems that swirl or turbulence should also be contributive towards easy starting.

What is rather astonishing to me is the wide range of difference in performance between the engine types; this will certainly be noted by many. Many operators of service fleets will be wanting to know which is engine F and which is engine B. The paper provides much food for thought for engine designers, and I hope they make full use of it.

G. KINNER: When reading a paper recently on the low temperature starting performance of petrol engines, I noted that four main factors were mentioned. These were rated in decreasing order of importance as follows: (1) engine design, (2) operating conditions, (3) fuels, (4) lubricants. It seems from the present paper that a similar rating obtains for diesel engines and, in view of Mr Lowe's remarks, it would be interesting to know how far the authors agree with such a general conclusion.

P. R. PRICE: There is considerable interest in starters of the inertia type and the cartridge type, which give high cranking speeds for short durations, and I should be glad of any further information the authors can give on the relative advantages of high cranking speed as compared with long cranking endurance.

I should also be interested in any information the authors can give on the effect of the Pintaux nozzle.

L. D. DERRY, replying to the discussion, said: We have been asked by Mr Brewer whether our conclusions would have been different if we had made comparisons of fuel starting performance at lower temperatures. Actually, we have done this; in fact, we got down to conditions under which the engines would only just start, even with cranking times as long as 2 minutes in some cases, and the conclusions were substantially the same. Some results were then masked by the effect of cloud point. Under these conditions the engines showed varying behaviour, particularly with regard to motoring speed and temperature. The motoring speed of some engines dropped off only slightly with temperature, whereas in others the motoring speed dropped off more rapidly. In one case it fell from 200 to about 30 r.p.m. for a 5° F decrease in temperature; a most amazing drop in that particular case.

In general, starting becomes difficult in the class of engine we are discussing at temperatures of about 10° F. For starting at temperatures as low as −20° F, as Mr Brewer is suggesting, it is felt that special starting aids, such as the ether carburettor, are essential. Even using such aids special precautions, such as the use of low viscosity lubricating oils and perhaps larger starter motors and batteries, would probably be necessary to ensure adequate motoring speed and good starting performance.

Another point is whether we have made too much of ignition quality in regard to starting performance. Certainly all the engines except one—and even that at lower cetane numbers—showed some preference for increased ignition quality. So that I think one would say in that case that it is the most important property, although this does not necessarily mean that a high cetane number fuel is essential in order to obtain good starting performance.

We have made tests with artificial starting aids, but these are not referred to in this paper, which deals only with the behaviour of commercial engines as these are supplied to the user. The only starting aids employed in the work described here were those devices fitted to the standard engines and these are, in some cases, essential to obtain a start, particularly at low temperatures and with the indirect injection engines.

Besides the chronographic recorder a tachometer was also used; this latter giving a direct measure of the mean motoring speed over a period. The chronograph, however, enabled more detailed information to be obtained on the fluctuations in speed during the whole starting time.

As stated in the paper we have found experimentally that the more volatile auxiliary fuels give better starting assistance. This may merely be because they vaporize and burn more completely in the manifold and the maximum amount of heat is therefore supplied to the cylinders. It must be remembered that auxiliary fuel is injected and burned only intermittently in the manifold. With heavier fuels burning may not be complete in the manifold and the flame may be quenched on reaching the cooler parts of the engine.

We were asked by Mr Pleeth if we should not have compared the viscosities of the fuels at the minimum starting temperature rather than at the more conventional temperature of 100° F. We actually made such a comparison, although the figures are not reported, and the results came substantially in the same order.

We would agree with Mr Withers that the increase of injection pressure

which occurs with over-fueling would result in better atomization and consequently more rapid vaporization and combustion of the fuel droplets. At the same time an increased quantity of fuel injected will increase the number of droplets present, and these two effects probably combine in improving starting behaviour.

With regard to the second point raised by Mr Withers, it is normally the case, that with a high viscosity fuel, atomization is poorer and starting might be expected to be more difficult. The relation between viscosity and volatility for conventional fuels is, however, so close that it is not normally possible to distinguish whether decreased viscosity or increased volatility is a major factor in improving cold starting. On the other hand, considering the mechanism of the vaporization and combustion of droplets it would seem that volatility itself is of some direct importance.

Information concerning cranking speeds was asked for by Mr Vulliamy. As would be expected, these varied considerably in the different makes of engines, being as high as 200 r.p.m. in one case and as low as 70 to 80 r.p.m. in another.

All the engines in Table IV can be regarded as being fitted with some kind of excess starting fuel device, but the quantities of excess fuel vary considerably in the different makes of engines, and these variations are reflected in the cold starting results obtained.

We agree with Mr Vulliamy's remarks regarding the performance of engine D without a heater. In this case burning oil (kerosine) gives a better cold starting performance than a vaporizing oil as an auxiliary fuel. Undoubtedly this can be attributed to the higher ignition quality of the burning oil, which had a cetane number of about 55, compared with only about 30 for the vaporizing oil. Without the heater element the pumping of the fuel into the manifold is in itself an excess starting fuel device. If diesel fuel is used in place of burning oil, with the heater element, the starting performance deteriorates slightly, but the engine still starts well. We tested auxiliary fuels of much lower volatility than that of the conventional diesel fuel in this engine and we still obtained good starting.

In reply to Mr Garton, none of the fuels reported here contained additives, although we have from time to time made some tests using different materials of this type.

Two of the three indirect injection engines tested are of the air cell type, while the third approximates to the "pepper-pot" variety. We do not know of any diesel engine which starts better on lower cetane that it does on higher cetane number fuels. There are, however, certain types of engine which, under normal running conditions, do operate more satisfactorily on the lower cetane number fuels.

In connexion with the fractionation of the fuels, we have the cetane numbers of the cuts, and the cetane numbers of the fuels from which the cuts were made, but have no data on the varying percentages of residue. It is not, therefore, possible to determine whether the effect noted by Mr Garton would apply in the case of the fuels examined in this work. It is of interest, however, that the cold starting performance of the fuels from which the cuts were made corresponds roughly with the 288° to 343° C cut, whereas one might have expected a correlation with the 230° to 288° C cut.

With regard to the effect of cloud point on the blocking of the filters,

raised by Mr Barrett, we have not so far made any measurements of the amounts of fuel delivered at temperatures below the cloud point; it is one of the things we hope to do.

It was suggested by Mr Lowe that a speed of 160 r.p.m. is faster than one would expect in an automotive engine at a temperature of 20° F. We agree that for some engines this would be the case, but for the multi-cylinder engines tested (all well-known commercial types) the mean motoring speed at 20° F would not be very much lower than the speed of 160 r.p.m. used in the single-cylinder tests. The answer given to Mr Brewer concerning performance at lower temperatures will cover also the answer concerning lower motoring speed; naturally there would be a lower motoring speed at lower temperatures.

We have no figures available on the actual amounts of leakage for the various fuel pumps used. We do know, however, the effect of viscosity on the relative leakage, in that, for example, a difference of 11 per cent is obtained in Engine E when changing the fuel viscosity from 1·8 to 3·9 centistokes.

We have made no attempt to correlate air movement with starting performance. All our work was done in standard engines as manufactured, and we tried to find out how they varied with respect to fuel characteristics.

The question of the relative importance of engine design, operating conditions, fuel and lubricant used, has been raised by Mr Kinner. In some cases fairly firm conclusions can be drawn from the information given in the paper. We have shown that the cold starting performance of different engines varies considerably, and that different design features affect their behaviour with respect to fuel characteristics. I think this only serves to emphasize that all concerned have to co-operate—the operators, the engine manufacturers, and the fuel and lubricant suppliers—in order to achieve the best results.

We were asked by Mr Price whether we had experience regarding the relative advantages of inertia and cartridge type starters, and whether we were in favour of a high speed motoring of short duration, or a long cranking period at a relatively low speed. We have recently made some measurements of compression pressures at different motoring speeds, and the results obtained indicate that compression pressures, and consequently compression temperatures, rise very sharply with increase of motoring speed up to about 200 r.p.m. At this speed the curves appear to flatten out, only small increases in pressure being obtained with increased motoring speed. I feel that if we could attain this speed as a minimum, cold starting would be relatively easy. Even so, the period for which an engine requires motoring varies considerably, but this makes it difficult to give a general statement on the relative advantages of cranking speed and duration of cranking.

We have not made tests with the Pintaux; as indicated, we experimented with standard engines.

Dr E. B. Evans: There are a few points to which I may refer, in addition to what Mr Derry has said. One or two speakers have referred to the relative importance of ignition quality in the starting of engines. A point I should like to make is that, if the compression temperature is high enough, cetane becomes of much less importance and ultimately disappears as a

factor in starting the engines. It does not matter how that higher compression temperature is achieved, whether by high compression ratio, or by high motoring speed, or by putting in heater plugs, but the higher it is, the less important will ignition qualities become.

Reference was made by Mr Withers to the relative effects of volatility and viscosity in connexions other than the volumetric efficiency of the pump. I think both these factors must influence quite largely the amount of fuel which actually vaporizes. As has been pointed out, the better atomization of lower viscosity fuel will promote the more rapid decay of the droplets, and the volatility associated with the lower viscosity will also tend to give vapour more quickly.

Then Mr Garton raised the very vexed question of additives. We purposely avoided bringing those into this discussion because the situation is still very complex. Additives used for raising the cetane number are quite liable to be of no use at all from the point of view of improving starting qualities. An addition of (say) 1 per cent of the nitrates, nitrites, and nitro compounds may raise cetane number by perhaps about 10 units. Materials such as the ethers may sometimes lower the cetane number, but they have been shown to improve startability. That applies through the di-ether up to the di-ethylene-glycol ethers as used by the Germans in the ring process. The explanation is not obvious, but it may be merely that the compound reacts or decomposes in a different temperature range. Why the nitrates and nitrites do not improve starting is rather a puzzle. I do not know whether or not Mr Garton has any explanation of that, but I rather fancy that the nitrates do not begin to exert any influence on the oxidation behaviour of the fuel until the temperature is quite high; at the low temperatures of starting (say) 300° lower, they seem to have no bearing at all. Peroxides seem to have some slight effect on startability; but the ethers, which one would imagine to be the most stable, seem to be the most effective class. The reason for that has puzzled me very much, and Mr Derry and I would be glad if anyone could offer an explanation.

THE PRESIDENT: We are so accustomed to seeing diesel engines start very easily on our highways that we rarely pause and wonder why. It is not until we have before us a paper such as that presented this evening that we begin to realize the amount of research that is devoted to diesel fuels by the petroleum industry; and even from a paper such as this I do not think the outside world would get a true perspective without also paying a visit perhaps to one of the research centres to see the amount of experimentation and diligent research which is carried out by those master minds working there. To say they are master minds is no exaggeration; the diesel engine could never have attained its present high position without the aid of those experts within the petroleum industry. If I were speaking to the automobile Division of the Institution of Mechanical Engineers I should make precisely the same pronouncement without fear of contradiction; I feel very strongly about the value and importance of the research which is being carried out by the petroleum industry.

Those of us who have had the privilege of visiting some of the big research establishments in America must have been very much impressed by the amount of time and energy they have devoted to the investigation of the

cold starting of both the gasoline and the diesel engine. Some may say that the temperature differences there demand it. But I would remind you that the research laboratories are not merely catering for Great Britain, where starting difficulties are not so pronounced as in other parts of Europe. Their horizon is beyond these shores; and if you think that possibly they have been a little parochial in their outlook, I ask you to remember that they are thinking of the colder countries as well as our own, for then you will gain a better appreciation of the work they have done.

It has been our privilege this evening to hear about some of the work they have done, and also their accomplishments, and I feel very proud to be able to thank Dr Evans and Mr Derry for having brought to our notice the results of their efforts. On behalf of the Institute of Petroleum I ask you to accord thanks to them for having given us this very valuable paper.

(The vote of thanks was heartily accorded.)

A SYMPOSIUM ON THE TESTING OF TEMPORARY CORROSION PREVENTIVES.

A MEETING of the Institute of Petroleum was held at Manson House, 26 Portland Place, London, W.1, on March 29, 1950, at 2.30 p.m.

The PRESIDENT OF THE INSTITUTE (Mr E. A. Evans) opening the meeting, said :—

It is our pleasure this afternoon and evening to hear several papers on the testing of temporary corrosion preventives. I have been tremendously impressed with the useful substance there is in them.

It is not the time to thank those who have contributed to this meeting, that will be done at the end, but I think we must just pay a small tribute at this stage to Dr Clayton and Mr Steet, who have done so much in organizing this symposium. They have performed a colossal task. In symposia of this kind you do not get papers together like this unless you put in an enormous amount of work, and I think you will agree with me that it is proper that Dr Clayton, who has done so much of the preparation, should be called on to occupy the Chair.

DR D. CLAYTON, taking the Chair said :—

The subject of the symposium is a very important one, and it is very topical. The export drive depends enormously on getting goods abroad free from corrosion and otherwise undamaged. Mr D. A. Williams gave a paper to the Institute * recently which emphasized the extreme importance in the case of oilfield equipment for work abroad. Moreover, engineering equipment for use in Great Britain must be delivered and kept in stores, often far from good; it must be kept in condition so that it does not need workshop time on it before it can be used. The problem therefore arises at home as well as abroad.

It is certain that a lot more will be heard of temporary corrosion preventives from now on, and the question of testing them is now of importance. Only the latter aspect is being considered in this symposium.

The Protectives Panel of this Institute has been active for about eighteen months, and has instituted a co-operative series of tests under sheltered conditions designed to provide basic data with which to compare laboratory results. It has also begun work on humidity cabinets. This work is inevitably required, but for the further programme it will be most valuable to have the information provided by this symposium available.

The first five of the following papers were then presented in summary by Mr W. R. Steet.

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* *J. Inst. Petrol.*, 1950, **36**, 309–25.

THE NATURE AND SCOPE OF TEMPORARY CORROSION PREVENTIVES.

By D. Clayton (Fellow) * and M. C. Thompson.†

Summary.

A description is given of the usual types of temporary corrosion preventives together with some of the newer developments. The field of use is defined, and the principal causes of failure reviewed; the contribution of important accessory properties is mentioned. Finally, some of the questions arising in accelerated testing are raised.

Introduction.

The broad function of temporary corrosion preventives is to protect metal surfaces against corrosion during transport and storage, in such a manner that articles can afterwards be restored to their original state by easy removal of the protective film, mainly by application of common petroleum solvents. Most of them function by providing a water-resistant barrier and by forming an adsorbed layer on the metal of naturally occurring or specially added inhibitors.

A brief description of the range of these corrosion preventives is thought desirable so as to indicate what is involved in the testing of them; the range of physical and chemical properties and corrosion-preventing properties is large. For the same reason the scope of their use, the causes of failure, and the properties accessory to direct corrosion prevention are reviewed.

Description of Common Temporary Corrosion Preventives.

There are many corrosion preventives on the market, and it would be impracticable to describe each kind individually; they can, however, be classified into fairly well-defined groups as regards the type of film formed, although there are in some cases intermediate ones. The most commonly occurring materials can be divided into soft-film, hard-film, and oil-film types, the soft films being further divided into solvent-deposited, hot-dip, smearing, and slushing types.

Soft-film Materials.

The cold-application, solvent-deposited types give a thinner film than the other soft materials, and somewhat inferior protection has to be accepted for this reason. They are usually based on lanolin or petrolatum, with such solvents as white spirit and coal-tar naphtha. The soft-film, hot-dip type is usually based on petrolatum, and the film may vary from a relatively hard, almost waxy, consistency to one nearly as soft as petroleum jelly sold for pharmaceutical purposes. It depends to a large extent on the blanket effect of the film for preventing corrosion, but may also contain specific corrosion inhibitors; film thicknesses of the order of $\frac{1}{2}$ mm are recommended, as against 0·02 mm obtained with the solvent-deposited type. With

* Imperial Chemical Industries Ltd. (Technical Department, London).
† Ministry of Supply.

uniform ½-mm films, protection for periods of upwards of 10 years can be obtained, but it is difficult in practice to attain this uniformity, and in the mass treatment of articles with this material failure can occur due to local thinning through a variety of causes associated with its soft nature.

The smearing types of material are usually lubricating-grease compositions, *i.e.*, blends of soap and lubricating oil, but may be mixtures containing petrolatum, oil, lanolin, or other fatty material. They are softer than the hot-dip type to enable this particular method of application in the cold. Between the soft, thick film and the thin, solvent-deposited types are the slushing compounds, which possess some flow properties at ambient temperatures, so that, when (for example) applied by brush, the brush marks soon disappear. They may contain a proportion of solvent, which evaporates after application, leaving a protective film similar to that of the smearing or even the hot-dip type. This type of material finds its most useful application on large, heavy machinery requiring protection of particularly large areas either during storage or during intervals of idleness in a machine shop; the effect of dust and dirt contamination should, therefore, be a factor to be taken into account when assessing the value of these materials.

The special castor-oil grease for metal components associated with rubber comes in the class of soft materials; it may be applied by smearing or hot-dipping. It will require special attention if performance testing is undertaken, not only because of association with rubber but also because castor oil is more prone to deterioration by oxidation than petroleum-base materials. Another material in this soft-material class presenting somewhat similar problems is the white-lead and tallow mixture, which has had a vogue for the treatment of heavy equipment parts; this, however, is of indefinite composition and variable properties.

Hard-film Materials.

The hard-film type comprises those materials which have been developed to avoid messiness in handling and contamination of adjacent objects. The films are deposited in the cold from solvents, and after drying should be tough, neither sticky nor brittle. The film-forming ingredients are plasticized resins, bitumens, and the like, according to the subsidiary properties required in the way of transparency, etc., and the solvents used vary according to the solubility of the ingredients and the allowable drying time. Like the solvent-deposited, soft-film type, it is economical as regards consumption of raw material; being also applicable cold, these two are the most widely used.

Oil Types.

Oil-type protectives, as their name implies, give fluid films, and their protective properties are not nearly as great as those of the materials giving solid films. For general purposes they are medium- or low-viscosity mineral oils containing specific rust inhibitors. In spite of their poor protective properties, they have their definite field of use on internal surfaces of tanks and certain assemblies, and on parts where solid material or solvents could not be tolerated. Because of their lower protective power, and also because the modes of failure might be different from the solid-film

types, it is generally agreed that accelerated testing of their rust-preventing properties should be tackled by different methods from those being developed for the latter. As sometimes the oil must also serve as a lubricant, *e.g.*, in hydraulic systems, or in engines where there will be contact with leaded-fuel residues, there will be occasional need of special tests for these purposes.

New Materials.

Amongst the most promising new materials which have come to the fore in recent years are the strippable-coating types, applied by hot-dipping. They rely on the formation of an impervious barrier rather than on any specific rust-inhibitory properties, and give thick, tough films which afford a very much higher degree of protection against mechanical damage than any of the types previously described; this property also enables expensive packaging material to be dispensed with, and this compensates in many applications for their high cost. These materials are based on ethyl cellulose or cellulose acetate–butyrate, and contain varying quantities of plasticizers, resins, and stabilizers, together with a proportion of fatty or mineral oil. The coating being thick and so tough that local thinning does not occur, a standard of rust prevention is attained which may necessitate differences of testing technique. To overcome the difficulties of application (special thermostatically controlled baths are required by the ethyl cellulose material, and the temperature of application is about 175° C), materials giving a strippable film deposited from a solvent or from an aqueous emulsion have been put on the market; however, thinner films are then usually obtained, and there is some loss of mechanical protection. Moreover, some of the solvent-deposited types tend to retain bubbles due to high viscosity and also to " tail " badly. The aqueous emulsion type is based on rubber latex with the addition of water-soluble inhibitors; they cannot be used with yellow metals.

Another type of material of recent introduction is the vapour-phase inhibitor; this overcomes many of the disadvantages of the normal films, *e.g.*, necessity for and difficulty of removal, and inconveniences in use. Small quantities only are necessary, and direct contact between solid inhibitor and the metal is not necessary. Hermetic sealing is not required, although there must be some restriction of circulation of air. It can be used as an impregnant of wrapping-paper, in the solid state, or in an alcohol solution. The unique physical state in which it functions and the smallness of the quantities required, again raise the question of testing technique.

Of the recently publicized materials the aqueous-phase corrosion preventives, sodium benzoate and sodium nitrite, should also be mentioned. In water solution they may serve some of the purposes of oil-type protectives; sodium benzoate has been used as an impregnant for wrapping papers, and the sodium nitrite as a water-based paste competing with soft-film protectives.

Scope of Materials.

In considering the scope of these materials, the differentiation from the more permanent paints and varnishes should be kept clear; the latter should be applied wherever they can be, and the temporary metal pro-

tectives only used where removal is subsequently necessary for the fitting or the working of the surfaces to which they are applied. In their normal thicknesses the general run of temporary corrosion preventives are not suitable for outdoor exposure, and they should always be protected against gross liquid water by appropriate coverings or wrappings. (The petrolatum-based, thick-film materials, and, in some cases, the greases, can be employed to protect equipment stored outside by applying them in extra thickness on the surfaces and filling crevices to prevent water access, but these cases are best left as exceptions. A separate test can be used for this application, but should not confuse the general issue.) No blame should therefore be attached to a temporary protective which fails on exposure outside in either storage or transit, or which is in contact with water-logged wrapping or cushioning material (it is still common to find steel articles arriving in hay, sawdust, or hessian that has become saturated with rain-water); it is considered that these conditions are too severe for this general class of materials at the present stage of development. It is also a vital requirement that the protective coating should be applied to clean and dry surfaces, and too much stress cannot be laid on this necessity; the fact that certain materials have finger-print removing or neutralizing properties, or water-displacing properties, should not be allowed to confuse this issue.

It is generally agreed that these coatings must protect the usual engineering materials against corrosion due to a humid atmosphere, in rural and in general industrial conditions (though not to especially severe conditions of certain individual works) during transit and storage; up to a temperature of 100° F (38° C) for tropical conditions. There may be condensation of moisture, generally in mist form, and sometimes this will lead to odd trickles of water down inclined surfaces. Works with especially corrosive atmospheres (worse than the general atmosphere of industrial towns and cities) should take their own special precautions to avoid an uneconomic general standard being set; also with present materials it is not possible to cope with salt spray, and for sea transit it is therefore necessary to rely on packaging to exclude this corroding medium.

Causes of Failure.

Failure may occur due to inherent inadequacy of the material, inevitable difficulties in application, carelessness in application, and exposure to unreasonably severe conditions. In attempting to draw conclusions from practical experience, it is usually found that the last two causes are so common that deductions under the other two headings are impossible. (The Institute's Protectives Panel has decided that it must start *ab initio* by doing "field" tests to establish the behaviour of a typical series of protectives in various parts of the country, to secure representative atmospheres, and have some basis of comparison for the laboratory tests.)

Of the failures from practical factors difficult to avoid, those from thin places in the films (due to contact in dipping between articles or between the article and the dipping basket, or due to a soft film being squeezed down at contact with the package, or due to handling) should receive proper attention in testing, *e.g.*, by simulation or by determination of an actual

thickness/protection curve for each material. A protective with good surface-active properties is more effective than one depending solely on a "blanket" effect when this thinning can occur. Scraping in transit and in stacking is common, as well as thinning due to contamination with grit and dirt, or insects, by which access of the corrodent to the metal surface is facilitated. It might be claimed that the latter difficulties should be safeguarded by packaging; there is much to be said for this view, but it appears that, at least in this country, articles will for some time be both transported without complete coverage and stacked on shelves in stores, and therefore liable to accumulate dirt particles. No tests have yet been suggested to cope with these conditions.

Accessory Factors in Corrosion Prevention.

There are numerous accessory causes of failure which are to be avoided. Hard films may be brittle and flake off on casual contact of articles with each other; they may remain too sticky, thus becoming particularly liable to dirt accretion, and to make wrapping-paper stick to them and pull the film away from the metal; they may age to an insoluble condition, and thus become difficult to remove with the common petroleum solvents. Soft films may have too low a melting point for tropical conditions; hard films may not remain flexible and adherent at low temperatures, and particularly the very low temperature in air travel. Moreover, there is an obvious need in general for good wetting properties on the part of the material as applied; there must be good adhesion after evaporation of the solvent or after setting; the material must acquire the intended consistency or must dry in the required time; and so on. Sometimes there are other properties combined with corrosion prevention needing testing, *e.g.*, water-displacing properties of certain thin soft-film (and latterly hard-film) types, the fingerprint neutralizing or suppressing properties of the thin, soft-film materials, the ability to neutralize residues from leaded fuel, and the engine behaviour of certain oil-type protectives, etc. Some of these points call for special tests; others can be assessed by already standardized means.

Acceleration of Testing.

Where the time factor is important, as in the humidity tests, the question of acceleration arises in order that the tests shall be completed within a reasonable time. As in many other fields, this point is one of considerable difficulty, and is therefore mentioned in this introductory paper. An attempt has been made above to define broadly the conditions reasonably to be met by these materials, and the question arises whether there is some means of accelerating the deterioration without the results being different from those in practice. Thus, in the case of mist condensation on surfaces, should it be formed on the surfaces and evaporated off again many times a day in the laboratory instead of (say) once a week or once every three months on the average in practice, or should the mist be formed initially on the surface and then maintained there by keeping the humidity in the surrounding atmosphere high, or should the condensation be continuous so that the liquid is constantly streaming off the test panels? Is the salt-spray test permissible to represent the acceleration of plain-water corrosion?

Can the concentration of SO_2 in an industrial atmosphere be multiplied in the laboratory test? Is the elevation of temperature above that in the practical case permissible as a means of acceleration, and, if so, how much? Is the use of mild-steel specimens permissible to represent the general run of ferrous metals, some of which have inherently better corrosion-resisting properties, and can a sensitive finish be used? Conversely, is it justifiable to use panels with edges neglected to represent engineering components with multiple edges (of usually definite radii)? A close examination of the position is obviously necessary, and it is hoped that in this symposium there will be a full review of experience and ideas on testing to help to establish a satisfactory position.

ACKNOWLEDGMENT.

Acknowledgment is made (M. C. T.) of the permission of the Chief Scientist of the Ministry of Supply to present this paper.

ASSESSMENT OF THE PROTECTIVE VALUE OF TEMPORARY CORROSION PREVENTIVES (WITH PARTICULAR REFERENCE TO HUMIDITY CABINET TESTS).

By T. G. CLINTON.*

SUMMARY.

The factors likely to produce breakdown of temporary corrosion preventives under Service conditions are considered, and certain performance tests applicable to the assessment of the protective qualities of such coatings are discussed. The use of a humidity cabinet and an intermittent salt-spray test are described in detail. Accelerated weathering, continuous salt-spray, and natural weathering tests are mentioned. Finally, the view is expressed that at present there is no individual performance test available which is likely to forecast the behaviour of protectives under all types of service.

INTRODUCTION.

PERFORMANCE tests required for assessing the protective properties of temporary corrosion preventives can be divided into two main groups :—

(1) Accelerated tests specifically designed to assess the intrinsic protective value of a material under known conditions.

(2) Tests designed to exercise day-to-day control of quality of products of known composition, *i.e.*, to cover variations in raw materials and/or manufacture.

The tests employed in the Ministry of Supply for specification purposes have to date fallen primarily into the second category, although it is felt that

* Chemical Inspectorate, Ministry of Supply.

the results of such tests are not widely divorced from the performance of the materials in normal Service use.

Temporary corrosion preventives can, in once sense, be divided into two main classes :—

(1) Those designed to protect stores which, in addition to being coated with protective, are packed into crates or cartons which, themselves, afford considerable protection from the elements.

(2) Those intended to protect stores which may, at some period, be exposed to the elements.

It is obvious that the factors liable to cause corrosion may be entirely different in the two classes, and this must be taken into consideration in deciding on methods of test.

In the case of protectives falling into category (1), *i.e.*, packed stores, the main cause of failure appears likely to be due to the action of water vapour, which permeates through the packaging, building up high humidity which when chilled produces condensation on the protective surface, although leakage of liquid water, contact with wet wrapping material, etc., are also possible. Whilst the resistance of the final protective coating to moisture penetration appears to be the prime criterion of protective quality, experience suggests that very different effects will be obtained from different types of wetting, *e.g.*, by placing drops of water on the film, immersion, or condensation, particularly if associated with elevated temperatures. Examination of packages returned from tropical exposure have shown evidence of copious condensation, *e.g.*, inside crated vehicles, and it is felt that exposure in a humidity cabinet of the type described below caters for this form of attack.

Protectives falling into category (2), *i.e.*, those liable to be exposed to the elements either directly to full weathering or on shelves in stores, etc., have to combat an entirely different set of conditions. Amongst factors likely to affect such stores may be any one or more of the following : exposure to rain, salt-spray, ultra-violet light, polluted atmospheres (either gaseous or dust laden), greater rates of temperature change, etc. It is felt that exposure in a humidity cabinet alone will not necessarily be of great value in assessing the ability of a protective to withstand such conditions, and, in fact, from the known wide variation in results of full exposure in different localities, it appears to be extremely unlikely that any single test other than long-term exposure on an actual site would provide the answer in any particular case, *e.g.*, under desert conditions, where resistance to abrasion may be extremely important.

Selection and Preparation of Test Specimens.

Before reviewing some of the tests which have been employed in the Chemical Inspectorate, Ministry of Supply, it may be useful to indicate how test specimens are normally prepared for exposure.

The work has been essentially confined to the testing of protectives for ferrous metals, and the following procedures have been used in order to standardize testing as far as possible :—

Quality of steel. A low-carbon steel complying with BS/ST/970 EN.2A/1.

Size of test specimen. Normally, a panel 6 in × 4 in × 18 B.G.

Surface preparation. The steel sheet as supplied by the manufacturers shows considerable variation in surface finish, and the panels are prepared as follows. The neutral mineral oil in which the panels are stored is removed by wiping with a cloth, and the panels are abraded first with No. 1 emery cloth and then with No. 0, finishing with a circular motion until the surface is covered with circular burnishing marks superimposed on each other. Emery dust and grease are then removed by swabbing with a cloth soaked in toluene, and the panel rinsed in methanol (74 O.P.), finally drying in a current of warm, dry air for a few minutes.

Application of protective. The specimens are coated immediately after preparation, using the appropriate method of application for the type of protective under examination. Normally the coating thickness is that at which the protective is applied in practice, and the coated specimens are allowed to stand at 60° to 70° F and 60 to 70 per cent relative humidity for 24 hr before exposure.

Provided the procedure outlined above is followed and care is taken not to handle the specimen with the naked hand after the final cleansing, no difficulty obviously attributable to finger-printing or non-uniformity of surface has been observed.

Suspension of panels. Panels are normally stood in copper racks or hung on copper wires during exposure in humidity cabinets and on glass rods or trays in salt-spray tests. There is no evidence of metal-to-metal contacts producing special corrosion effects in the humidity cabinet, but it should be stressed that attack within 0·25 in of the edges is normally ignored.

Humidity Cabinet Testing.

As indicated in the introduction it was felt that a test under highly humid conditions (including condensation effects) is applicable to many service uses, and as cabinets covering such conditions were already in use in many widely separated laboratories it was decided to adopt them for temporary protective testing. As originally used the test required exposure of the coated specimen vertically in an atmosphere of approximately 100 per cent relative humidity at 45 $\pm$ 3° C, but experience showed that it was possible to maintain high humidity at a constant temperature within this range without appreciable condensation occurring on the test panels. The requirements were, therefore, modified to insist on the specimen being subjected to high humidity, whilst the temperature cycled from 42° to 48° C and back to 42° C. The majority of tests for reproducibility of results in such humidity cabinets have been carried out on paint films, and many types of apparatus, varying from simple wooden or metal boxes to a relatively complicated tunnel in which saturated air is circulated at high speeds, have been found to give similar results. The construction of two cabinets which have been used in our laboratories is shown in Figs. 1 and 2. In carrying out check tests in different laboratories from time to time various adjustments have been required to cabinets of differing types and the desirability of amplifying the specification has recently been considered. It was felt, however, that insistence on any particular design of cabinet should be avoided, as this would involve the replacement of many individual cabinets which are

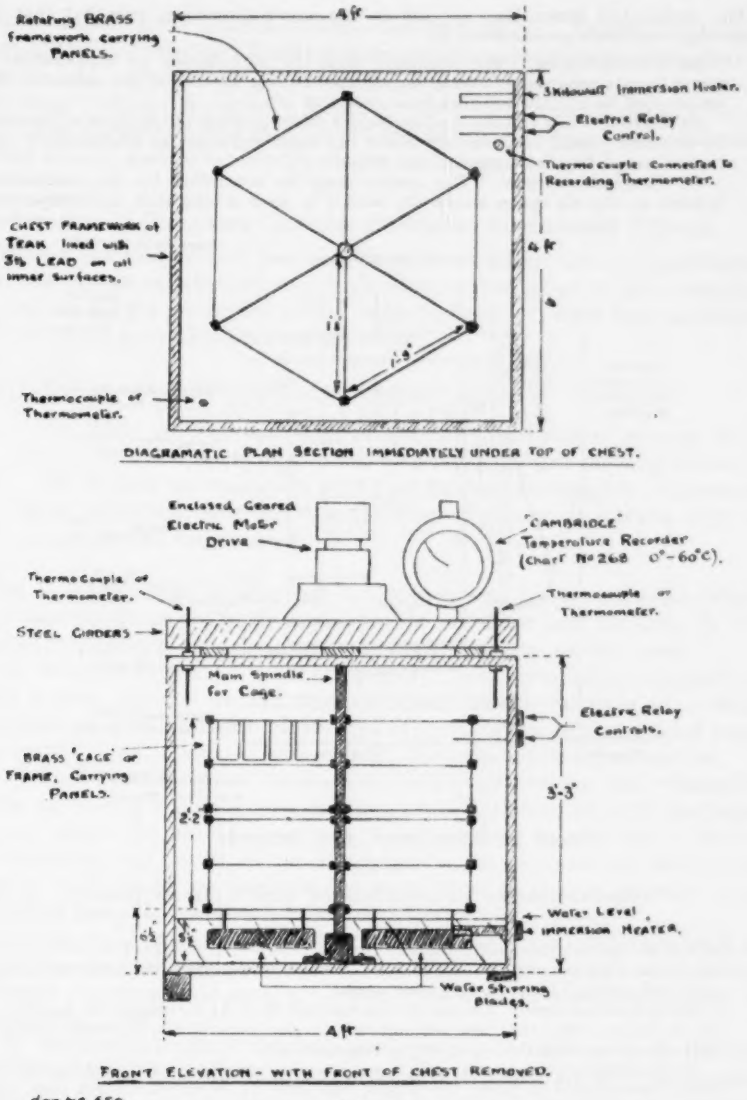

Rotating BRASS framework carrying PANELS.
4 ft
3 kilowatt Immersion Heater.
Electric Relay Control.
Thermo couple Connected to Recording Thermometer.
CHEST FRAMEWORK of TEAK lined with 3/16 LEAD on all inner surfaces.
4 ft
1'6"
1'-9"
Thermocouple of Thermometer.
DIAGRAMATIC PLAN SECTION IMMEDIATELY UNDER TOP OF CHEST.
Enclosed Geared Electric Motor Drive
"CAMBRIDGE" Temperature Recorder (Chart No 268 0°-60°C).
Thermo Couple of Thermometer.
Thermocouple of Thermometer.
STEEL GIRDERS
Main Spindle for Cage.
Electric Relay Controls.
BRASS 'CAGE' or FRAME, Carrying PANELS.
2'2
3'-3"
Water Level & IMMERSION HEATER.
Water Stirring Blades.
4 ft
FRONT ELEVATION - WITH FRONT OF CHEST REMOVED.
SER No 650.

FIG. 1.

CONSTRUCTION OF C.C.I. MOVING FRAME TYPE HUMIDITY CHEST.

apparently performing quite satisfactorily. The following performance requirements for the cabinet have therefore been tentatively adopted :—

Draft Specification for Humidity Cabinet.

General. The apparatus shall consist of a closed cabinet in which the relative humidity is maintained at approximately 100 per cent, and the temperature cycles continuously over a range of 42° to 48° C, thereby ensuring that copious condensation occurs on test panels suspended vertically within the cabinet.

The design and dimensions are left to the user's discretion, provided that the following conditions are observed :—

(a) *Humidification.* The humidity shall be maintained by evaporation of water from a reservoir covering (or situated in) the bottom of the cabinet. The water shall be maintained free from grease or oil.

(b) *Heating.* The cabinet shall be heated solely through the medium of the water by a heater placed immediately below the water reservoir, or alternatively by a heater completely immersed in the water.

(c) *Temperature cycle.* The heater shall be controlled by *two* thermostats (placed in the air space above the water) in such a way that the temperature

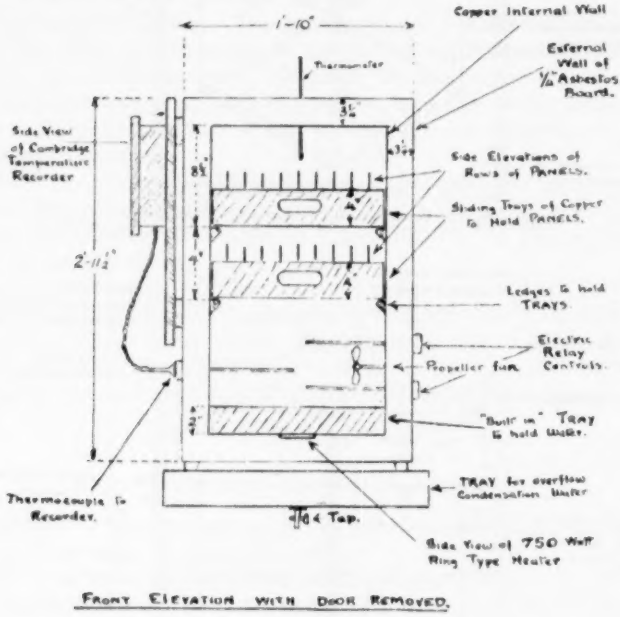

1'-10"
Copper Internal Wall
Thermometer
External Wall of ¼" Asbestos Board.
Side View of Cambridge Temperature Recorder
Side Elevations of Rows of PANELS.
Sliding Trays of Copper to Hold PANELS.
2'-11½"
Ledges to hold TRAYS
Electric Relay Controls.
Propeller Fan.
"Built in" TRAY to hold Water.
TRAY for overflow Condensation Water
Thermocouple to Recorder.
Side View of 750 Watt Ring Type Heater
FRONT ELEVATION WITH DOOR REMOVED.

FIG. 2.

CONSTRUCTION OF C.C.I. STATIONARY TYPE HUMIDITY CHEST.

of the air space cycles continuously from 42° to 48° C and back to 42° C in not less than 45 min and not more than 75 min. The times required for heating and cooling shall be approximately equal.

(d) *Air circulation.* The air in the cabinet shall be circulated by means of a fan in such a way that the temperature in any part of the air space shall not differ by more than 0·5° C at any given moment.

(e) *Spacing of test panels.* With cabinets as usually constructed it has been found inadvisable to place the panels less than 1½ in apart, or less than 1½ in from any side of the cabinet. This distance is, however, governed by the efficiency of the air-circulating device used.

Conditions Occurring inside a Typical Cabinet.

The conditions occurring inside a typical stationary type of cabinet have been investigated by following weight and temperature changes of a panel in relation to the air temperature. This has shown that condensation on the panel occurs almost solely during the time the air surrounding it is rising in temperature, and that during this period the panel temperature is

always a little lower than that of the surrounding air. During the cooling part of the cycle the panel temperature remains a little higher than that of the air, and, as judged by gain in weight, little or no condensation occurs on the panel during this period. There is no evidence that panels dry out at any time during the exposure, and it appears highly improbable that they could do so if saturation conditions are in fact maintained.

Performance of Temporary Corrosive Preventives in Humidity Cabinets.

Whilst the majority of the tests have been carried out as specification tests on known satisfactory materials which are required to give complete protection for the prescribed period, some further tests have been made and the following general comments are offered :—

(1) Breakdown is normally of two types :—

(*a*) With oils and materials of low-flow-point failure spreads down the panel and often is associated with drainage and washing effects.

(*b*) Failure on materials of higher flow characteristics is generally more uniformly distributed in the form of pitting or etching over the entire area of the panel.

(2) It is advisable to carry out control tests on known materials whenever new products are being examined, to allow for any variation in the extent or degree of attack which may occur between repeat tests.

(3) Results of extended tests have always been recorded as comparisons with known controls rather than as quantitative amounts of rusting, although an approximation of the area of metal found to be corroded when the tested panel is cleaned with solvent has sometimes been recorded.

(4) Direct correlation of results with field trials has not been attempted in the absence of a suitably standardized set of field conditions for packaged stores, where the humidity cabinet is expected to be a guide to service performance, but results on panels exposed in wooden packing-cases in the tropics have placed materials in the same order of protective value as in extended humidity cabinet trials.

(5) The test breaks down oil-type protectives too rapidly to enable it to be used as a specification test to distinguish between oils of known widely different performance in service. (An alternative test used for this purpose is described later.)

(6) Service materials known to give good protection are little affected in the cabinet, even on long exposure when tested at film thicknesses normally used. As the value of certain Service protectives, *e.g.*, mineral jelly and ethyl cellulose strippable coatings, is undoubtedly largely due to the moisture-proof blanket afforded by thick films there has been hesitation to rely on tests on unusually thin coatings of such materials.

Other Types of Test for Protective Properties.

Space limitation only permits these to be mentioned briefly, but others which have been employed occasionally are :—

Continuous Salt Spray.

This consists of exposure in a closed glass vessel to a baffled salt spray formed by atomizing the following solution :—

Calcium sulphate	1·3 g.
Magnesium sulphate	1·7 g.
Magnesium chloride	2·6 g.
Sodium chloride	21·4 g.
Water	1000 g.

Salt solution dripping off test specimens should not be recirculated, and panels should be supported at approx 15° from the vertical.

Accelerated Weathering.

Exposure in an apparatus as described in B.S.S. 987. The panels are fixed to the side of a drum which revolves slowly so that the panels are exposed to a fine spray of distilled water and then pass close to a 900-W enclosed D.C. carbon arc. The drum revolves once in 20 min.

Natural Weathering.

This has been of two types :—

(1) full exposure at 45° facing south ;
(2) under top cover suspended vertically.

These tests are considered to be only of limited value, unless the protectives are known to be likely to be exposed to such conditions in practice, and they have generally been used to ensure that the performance of new or alternative formulations under such conditions is not inferior to that of existing service materials. As would be expected, the results sometimes correspond with those of humidity cabinet exposure, but are sometimes very different. A noteworthy example of the latter is the case of certain inhibitors which appear to give protection in the humidity cabinet by the formation of stable emulsions, but which promote washing off of the film under accelerated weathering or in rainy natural weather.

Intermittent Salt-spray Test applied to Oil-type Protectives.

Finally, the following test appears to give good differentiation between oil-type protectives containing inhibitors and known to give good service in practice and the same oils without inhibitors. It is based on that described in B.S.S. 1391, which was originally devised in the Armaments Research Department, Ministry of Supply.

A steel panel prepared as described previously is coated with the material under test by dipping, and allowed to drain in a vertical position for 30 min at room temperature. Using a hand atomizing spray, and with the panel supported in a horizontal position, the upper surface is sprayed with a 1·0 per cent aqueous sodium chloride solution until a uniform droplet intensity (*i.e.*, droplet size and distribution) is obtained between the limits illustrated diagrammatically in Fig. 3.

Note.—*It may not be possible in some instances to assess visually the quantity of spray falling on the test panel owing to surface-tension effects, such as spreading of the water drops or emulsification. In these cases it is suggested that a suitably prepared " blank " panel on the surface of which the droplet intensity may be readily observed be sprayed side by side with the panel*

under test, it being assumed that the droplet intensity on the test panel is the same as that on the "blank."

Any small hand atomizer capable of giving a fine spray may be used. The jet should be held in the horizontal plane of the panel, 12 in from the centre of the panel, and inclined upwards at an angle of 30 deg so as to permit an indirect spray to fall naturally on to the panel, thus minimizing as far as possible forceful penetration of the protective film by the salt solu-

Maximum. Minimum.

FIG. 3.

DROPLET INTENSITY, INTERMITTENT SPRAY TEST.

tion. Spraying of the panel for a period of approximately 5 sec should produce the required droplet intensity.

The sprayed panel is then maintained in a *horizontal* position in a suitable cabinet under dust-free conditions at room temperature * and approximately 95 per cent relative humidity.

The panel is re-sprayed with 1 per cent sodium chloride solution as described above to maintain the required droplet intensity at 24-hr intervals throughout the test.

At the end of 336 hr exposure the upper surface of the panel is examined for signs of corrosion with the aid of a lens (magnification 8 ×), the protective film being removed with solvent if necessary.

CONCLUSION.

It should be emphasized that whilst it is felt that the humidity cabinet type of test gives a good indication of the value of a protective under packaged conditions, it is considered essential that it should be employed in conjunction with ancillary tests to cover such properties as adhesion, drainage at high temperatures, etc., unless it is felt that these points can be adequately covered by composition or limitations as to use of the protective.

For protectives on unpackaged articles there does not appear at the moment to be any universally applicable test, and recourse to improvization to meet the particular set of conditions envisaged is necessary on each occasion.

ACKNOWLEDGMENT.

Acknowledgment is made of the permission of the Chief Scientist, Ministry of Supply, to write and publish this paper.

* For the purpose of this test room temperature is taken to be 15·5° to 21° C (60° to 70° F).

USE OF WEATHEROMETER AND HUMIDITY CABINETS FOR EVALUATION OF TEMPORARY CORROSION PREVENTIVES.

By W. POHL * (Fellow).

INTRODUCTION.

THE need for accelerated tests to evaluate the protective properties of anti-corrosion compositions is evident. Even "temporary" corrosion preventives are expected to give protection for periods of time which would be inconveniently long for laboratory test purposes.

Weatherometers and humidity cabinets have been used extensively for this purpose, and the object of the present paper is to contribute to the discussion some of the experiences of a group of workers whose task was to develop water-displacing protectives of the soft-film, solvent-deposited type and corrosion-preventive oils, both with varying degrees of protective ability.

These terms of reference sound fairly simple and, apart from the provision of water-displacing properties, such as might have been fulfilled by a few variations in the amount of lanolin in solvent or oil. In actual fact, the work extended over some five years and involved the examination of between 500 and 600 blends. Being undertaken in the war and immediate post-war years, a good deal of investigation was necessitated by the elusive nature of commercial supplies of ingredients. Supplies of wool-grease derivatives, hitherto the main bases of corrosion-preventives, changed in nature and quantity in an Alice-in-Wonderland manner and, by the time an alternative was found, it, too, had an unpleasant habit of becoming unavailable.

In this paper the term "temporary corrosion preventive," or more shortly "corrosion preventive," will be used, following the practice of the B.S.I. Packaging Code 1133, to denote materials designed to afford temporary protection against the rusting of ferrous materials, and the term "protective agent" or more shortly, "protective" to denote the main active constituent of such compounded materials.

Before any type of accelerated test was used, some preliminary outdoor and indoor exposure tests were made on the basis of the U.S. Bureau of Ships Ad. Interim Spec. 52-C-18 (INT). Cylindrical test-pieces, 6 × $\frac{3}{4}$ in, were exposed: (*a*) under a roofed outdoor frame with open sides, and (*b*) in a somewhat damp, unheated brick outbuilding. Soft-film, solvent-deposited, and inhibited-oil types were exposed. All broke down within one month in the outdoor exposure tests during which heavy fog and much rain was experienced, and lasted four to six months in the indoor exposure tests. These tests gave some idea of the protective qualities of the materials in question, and were used as a basis for subsequent revised formulations and accelerated tests. Detailed records of the appearance of the test-pieces

* Shell Petroleum Co. Ltd.

were kept, but no particular system was employed. The results are summarized in Table I, which also includes subsequent weatherometer tests.

TABLE I.

Exposure Tests.

A–G : Soft-film, solvent-deposited.
H–M : Inhibited oils.

Protective agent.	Indoor exposure.		Outdoor exposure.		Weatherometer life, hr.
	Initial rust, weeks.	Condition after 26 weeks.	Initial rust, days.	Condition after 28 days.	
A	22, edge	No rust	28	1 spot	52
B	22, pin point	Few pin points	4	Light coat	74
C	11	Many pin points	4, heavy	Heavy coat	4
D	7	Much rust	4, light	Light coat	23
E	3	Few pin points	4	Light coat	39
F	>26	No rust	14, light	Slight	39
G	3	Much rust	4	Light coat	4
H	>26	No rust	7	Pin points	2
I	4	Pin points	4, heavy	Heavy coat	2
J	4	Pin points	4, heavy	Heavy coat	2
K	4	No rust	4, heavy	Heavy coat	2
L	4	Much rust	4, heavy	Heavy coat	2
M	9	No rust	4, heavy	Heavy coat	2

Initial rusting was assessed from the appearance of the coated test-piece, but the condition after twenty-six weeks was determined after degreasing the test-piece. This accounts for the two anomalous results where initial rust was recorded after a short period and "no rust" appeared after twenty-six weeks. There was evidence, however, of incipient corrosion.

As accelerated tests, a weatherometer was first used because it was already available, whereas a humidity cabinet was only acquired later. With both instruments conditions had to be explored and adapted, and the following sections deal with results obtained under standardized conditions of preparation and exposure of test plates unless otherwise stated.

WEATHEROMETER.

The available model of weatherometer consisted of a slowly rotating drum (1 rev in 12 min), $3\frac{1}{2}$ ft diameter, to which test plates could be attached so that they were continuously exposed to U.V. light from a centrally placed naked carbon arc and intermittently exposed (once every revolution) to a water-spray. The apparatus had the following defects which were avoided in a later model :

(*a*) The open form of arc and absence of automatic carbon-changing mechanism necessitated constant attention. Carbons had to be changed twice daily, which precluded the use of the instrument over week-ends. In recording results, both "exposure times" and

"standing times" were noted, but in general the latter were ignored, and all data given in succeeding tables refer to "exposure times."

(*b*) The water-spray consisted of a drilled pipe fitted direct to the mains supply. Uncontrolled fluctuations in the rate of delivery of water and in the character of the spray resulted from blockage of holes and fluctuations in mains pressure.

The later model had an enclosed arc and an air-atomized water-spray, but was no more repeatable or reliable as a means of assessing protectives.

Quantitative expression of results is difficult owing to the absence of any definite measurable quantity. Measuring the increase in weight of the test-piece on rusting is not practicable, since the obverse side of the test-piece rests on the drum. The recording of general appearance can be improved upon by counting the number of rust spots and perhaps measuring their diameter, thus giving a quantitative expression in terms of time to reach a certain state in the progress of corrosion.

Observation of the degree of rusting is sometimes difficult, and not infrequently what appeared to be rust spots when observing the coated test-piece have been shown not to be so on degreasing the test-piece. In all experiments where periodic observations are recorded the data refer to observations on the coated test-piece, except that the final observation was often checked on the degreased specimen.

From a practical point of view both the time elapsing before any rusting occurs and the general rate of rusting thereafter are of importance; which is the more important will depend on the application in question. "Initial rusting," however, is difficult to define satisfactorily from an experimental point of view. Owing to difficulties in ensuring uniformity of films, freak results are not uncommon, and there is an obvious difference in level of corrosion between two plates, one of which shows "initial rusting" by way of an odd spot on a certain day and nothing more for some weeks, and one which shows "initial rusting" as a spot on a certain day with a rapid progressive development during the succeeding days.

The definition of "initial rusting" as the presence of four small rust spots (diameter $\frac{1}{16}$ in) was thought to be a more reproducible indication of film break down, and the "life" ofa corrosion preventive was accordingly defined in this way. Some justification for this is shown in Table II, which

TABLE II.

Weatherometer—Average Deviation from Mean Life.

Protective.		Plates tested.	Aver. deviation from mean life percentage defined by:	
Code No.	Per cent.		Initial rust.	Four small spots.
1	15	22	66	46
2	15	22	114	105
3	15	14	92	83
1	35	12	59	43
2	35	13	31	25
3	35	7	56	39

shows, for tests on soft-film, solvent-deposited corrosion preventives, a lesser average percentage deviation from the mean "life" as defined by four spots that as defined by first appearance.

The average deviation is, however, of such a high order that it might be thought that the improvement is not significant. More detailed examination of results showed that the difference was real. On numerous occasions spots would form prematurely, and remain unchanged for considerable periods. (A similar use of three spots was mentioned by Floyd Todd, *Industr. Engng Chem. Anal.*, 1944, **16**, 194.)

On this basis, Table III gives results on six soft-film, solvent-deposited-

TABLE III.

Weatherometer "Life" and Deviation.

Protective.		Plates tested.	Life, hr.			Deviation from average.			
						Hr.		Per cent.	
Code No.	Per cent.		Aver.	Max.	Min.	Aver.	Max.	Aver.	Max.
1	15	22	26	54	12	12	28	46	108
2	15	22	58	278	12	61	220	105	380
3	15	14	48	150	12	40	102	83	212
1	35	12	88	174	24	38	86	43	98
2	35	13	376	608	296	96	232	25	62
3	35	7	398	618	180	155	220	39	55

type corrosion preventives showing the maximum, minimum, and average "life" values and corresponding percentage deviations. These results demonstrate that the weatherometer in question was unsuitable for the quantitative study of protection.

In spite of this general scatter of results over a large number of tests, duplicate results carried out simultaneously have generally shown good repeatability, as is demonstrated by Table IV, in which the life is shown for duplicate tests on corrosion preventives containing protectives Nos. 1, 2, and 3 in 15 and 35 per cent quantities (indicated by $\frac{1}{15}$, $\frac{1}{35}$, etc.).

That the weatherometer placed corrosion preventives in a reasonable order of merit was shown by comparing two series of corrosion preventives differing in the nature of protective agent, but in each of which the amount of protective was varied in steps of 5 per cent by wt. from 5 to 35 per cent. The protectives employed were those shown as Nos. 1 and 2 in Table III, and the results are shown in Table V.

Weatherometer results on the series of corrosion preventives shown in Table I also indicated some parallelism with the order of merit in the indoor and outdoor exposure tests, as can be seen by grouping the results into three categories as shown in Table VI.

On this basis, it was considered that, although the weatherometer was unsuitable for quantitative work in the sense that no absolute figure could be given for "life" which varied from test to test, it was suitable for qualitative studies and provided a reasonable basis of comparison.

The fact that "life" in terms of time to develop four spots had no absolute value and that it took no account of protective properties subse-

quent to initial rusting, led to the development of a graphical method of presenting results. Graphs were constructed plotting total hours of

TABLE IV.

Weatherometer—Duplicate Tests.

Protective Test No.	Life, hr.					
	$\frac{1}{15}$.	$\frac{2}{15}$.	$\frac{3}{15}$.	$\frac{1}{35}$.	$\frac{2}{35}$.	$\frac{3}{35}$.
1	48	24	126	24	312	312
	48	200	150	24	312	180
2	40	278	30	127	312	618
	40	278	30	127	312	618
3	30	30	12	24	296	280
	30	30	12	72	296	280
4	12	12	18	104	544	—
	12	12	18	128	608	—
5	18	18	18	78	336	—
	18	18	18	78	336	—
6	18	18	24	72	304	—
	18	18	24	104	360	—

exposure (ignoring standing) against a series of arbitrary states in the progress of corrosion. The spacing of the states along the y axis was logarithmic in that relatively small changes of state during the initial stages

TABLE V.

Weatherometer—Concentration of Protective Agent.

Protective, per cent.	Life, hr.	
	Protective No. 1.	Protective No. 2.
5	10	10
10	15	15
15	30	60
20	35	175
25	104	200
30	128	200
35	128	520

of corrosion occupies the same linear interval on the graph as a relatively large change of state during the final stages. This was done because :—

(*a*) The initial stages can be observed with greater accuracy, *e.g.*, by counting and measuring rust spots.

(*b*) The initial stages are of relatively greater importance for the assessment of protection than are the later stages of corrosion.

This type of record is illustrated in Figs. 1 and 2, corresponding with the two series with increasing amounts of protectives referred to in Table V, and Fig. 3 corresponding with a series containing 35 per cent by wt of various types of protective.

TABLE VI.

Indoor, Outdoor, Weatherometer Exposures.

		Category 1.	Category 2.	Category 3.
Indoor	Initial rust . . .	>20 weeks	6–20 weeks	<6 weeks
	Condition after 26 weeks .	No rust	Pin points	Much rust
Outdoor	Initial rust . . .	>20 days	6–20 days	<6 days
	Condition after 28 days	Pin points, slight	Light coat	Heavy coat
Weatherometer life . . .		>50 hours	5–50 hours	<5 hours

Corrosion preventive.	Category.				
	Indoor.		Outdoor.		Weather-ometer life.
	Initial.	26 weeks.	Initial.	28 days.	
A	1	1	1	1	1
B	1	2	3	2	1
C	2	2	3	3	3
D	2	3	3	2	2
E	2	3	3	2	2
F	1	1	2	1	2
G	3	3	3	2	3
H	1	1	2	1	3
I	3	2	3	3	3
J	3	2	3	3	3
K	3	1	3	3	3
L	3	3	3	3	3
M	2	1	3	3	3

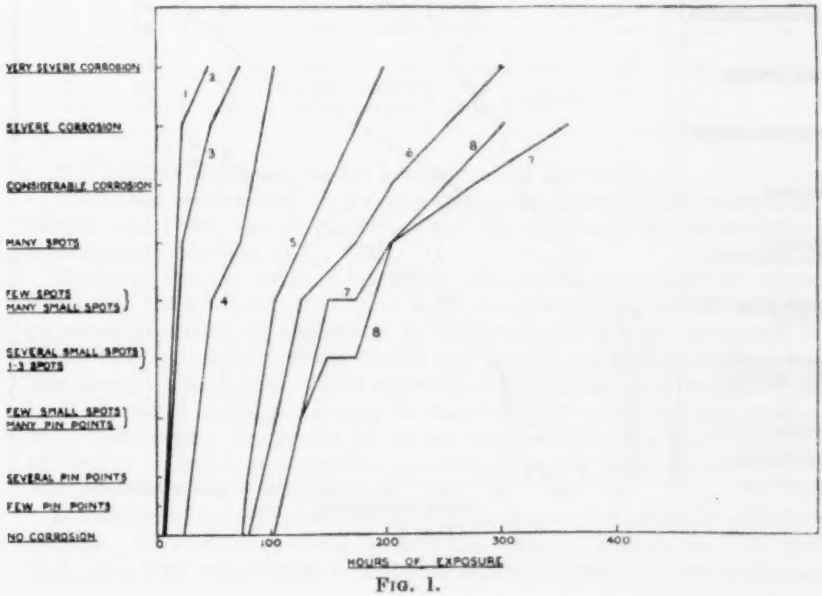


FIG. 1.

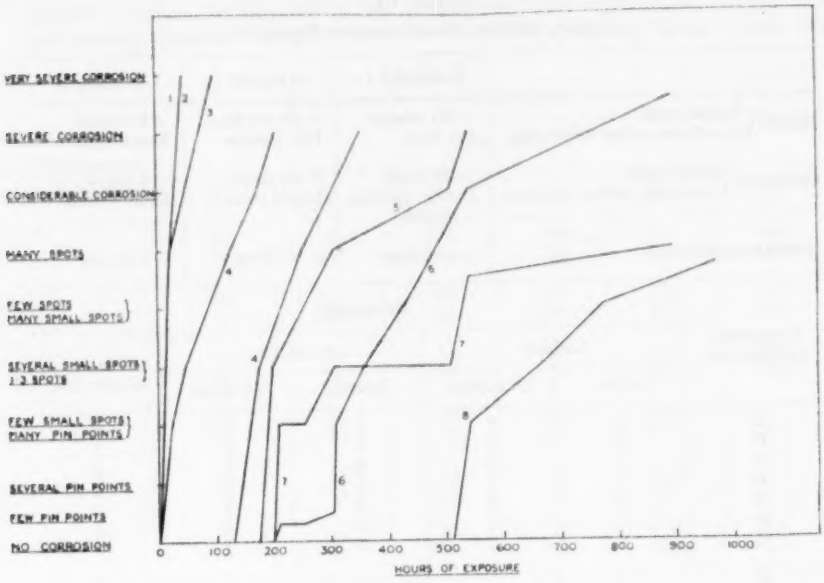

VERY SEVERE CORROSION
SEVERE CORROSION
CONSIDERABLE CORROSION
MANY SPOTS
FEW SPOTS
MANY SMALL SPOTS
SEVERAL SMALL SPOTS
1-2 SPOTS
FEW SMALL SPOTS
MANY PIN POINTS
SEVERAL PIN POINTS
FEW PIN POINTS
NO CORROSION
0
100
200
300
400
500
600
700
800
900
1000
HOURS OF EXPOSURE

FIG. 2.

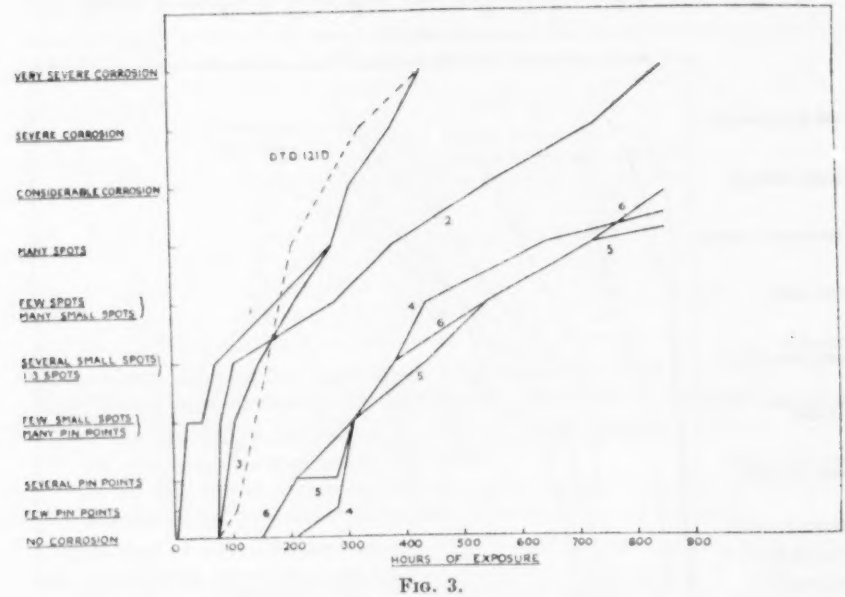

VERY SEVERE CORROSION
SEVERE CORROSION
CONSIDERABLE CORROSION
MANY SPOTS
FEW SPOTS
MANY SMALL SPOTS
SEVERAL SMALL SPOTS
1-3 SPOTS
FEW SMALL SPOTS
MANY PIN POINTS
SEVERAL PIN POINTS
FEW PIN POINTS
NO CORROSION
DTD 1210
0
100
200
300
400
500
600
700
800
900
HOURS OF EXPOSURE

FIG. 3.

Humidity Cabinet.

A humidity cabinet may be regarded as a testing device for accelerated corrosion tests under extreme indoor conditions (120° F/100 per cent relative humidity are typical cabinet conditions, and were used in the present investigations). Storage conditions in tropical zones are characterized by such conditions, and humidity cabinets may be expected to give some information as to the probable effectiveness of corrosion preventives.

Various types of humidity cabinet have been used by different workers; the one concerned in the present discussion was one commercially available in the U.K. The unit was one of the earliest models of its type, and later models are known to differ in certain details. The apparatus consists of a cabinet in which temperature and humidity can be controlled by means of electric heaters and by injection of steam. The air thus conditioned is circulated within the chamber by a fan. The test-pieces are suspended from rods in the chamber and observed periodically.

As with the weatherometer, attempts were made to obtain quantitative assessment of " life " in terms of time required to develop four small spots, and typical results are shown in Table VII.

Table VII.

Humidity Cabinet—" Life " and Deviation.

Protective.		Plates tested.	Life, hr.			Deviation from average life.			
						Hr.		Per cent.	
Code No.	Per cent.		Aver.	Max.	Min.	Aver.	Max.	Aver.	Max.
1	15	13	423	1128	15	262	705	62	167
2	15	16	>1010	>3572	120	—	—	—	—
3	15	10	> 740	1320	480	—	—	—	—
1	35	8	487	1008	48	319	521	65	107
2	35	12	>1800	>3572	912	—	—	—	—
3	35	10	>4540	>4540	4540	—	—	—	—

It is evident that quantitative results are not obtained.

Unlike the weatherometer, the humidity cabinet failed to give repeatable results, and there was frequently a wide divergence in the behaviour of duplicates as shown in Table VIII.

Moreover, the two series of materials, with increasing protective content which had given the expected order in the weatherometer, did not show the expected gradation of protection in the humidity cabinet, as shown in Table IX. Not only were the results very erratic but wide divergence was also shown by duplicates. This variation in results was also demonstrated by a graphical technique similar to that used for weatherometer results. Figs. 4 and 5 show the results for the two series with increasing amounts of protective in which the corrosion preventive power does not correspond with concentration of protective.

It is evident that different humidity cabinets can give markedly different ratings. Differences in rating by humidity-cabinet tests in the U.S. and U.K. have been experienced with several different types of protectives, *e.g.*,

TABLE VIII.

Humidity Cabinet—Duplicates.

$\frac{1}{15}$ = 15% *Protective No. 1, etc.*

Protective Test No.	Life, hr.					
	$\frac{1}{15}$.	$\frac{2}{15}$.	$\frac{3}{15}$.	$\frac{1}{35}$.	$\frac{2}{35}$.	$\frac{3}{35}$.
1	27	912	1008	48	1008	>3572
	912	912	>1008	1008	>2016	>3572
2	15	120	600	384	>3572	1008
	36	624	700	440	3572	>4540
3	340	520	>312	144	3000	1008
	340	520	>312	144	>3572	4540
4	>312	>312	1008	816	648	576
	>312	>312	1320	912	912	>2016
5	564	>3572	648	—	816	>1008
	530	>3572	480	—	1488	>1008

TABLE IX.

Humidity Cabinet—Concentration Protective.

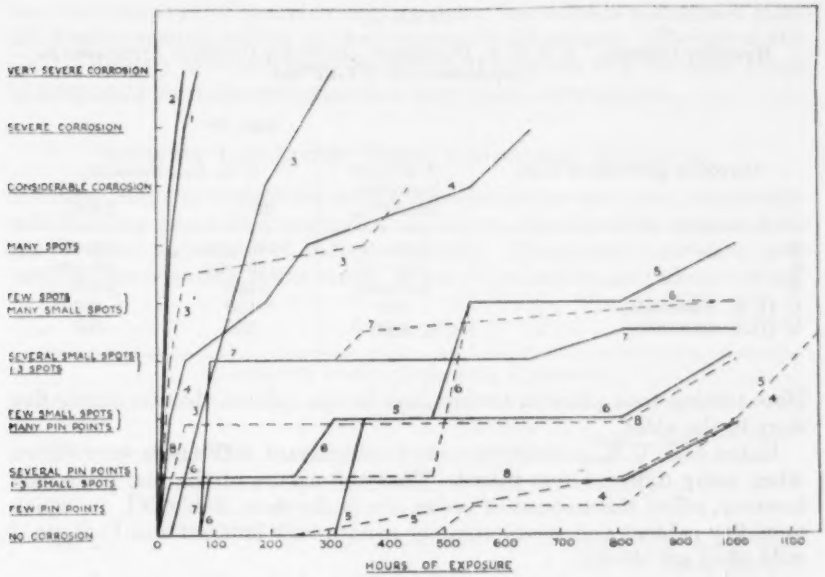
Protective, per cent.	Life, hr.	
	Protective 1.	Protective 2.
5	<3/<3	6/6
10	24/48	24/190
15	24/1000	800/800
20	360/1000	800/800
25	300/500	800/1200
30	95/95	>2000
35	48/900	>2000

inhibited oils to A.X.S. 674 and U.S. Army Air Force 3605 specifications, and soft-film, solvent-deposited types. It was shown that these differences were not due to differences in either test plates or ingredients, and it was concluded that they were due to differences in cabinet design and technique, one of the most obvious of which was the single passage of externally conditioned air in the U.S. tests and circulation of internally conditioned air in the U.K. tests.

Two soft-film-type materials which gave a " life " of respectively 400 and " a few " hours in U.S. tests, both gave a " life " of 380 hr in U.K. tests. Equal results were also obtained in U.K. weatherometer tests.

Differences in relative humidity between 95 and 100 per cent were found to cause marked differences in the assessment of materials developed to meet AN-VV-C.576a (Inhibited-oil Type) Specification (which specified 95 to 100 per cent humidity). This is shown in Table X.

Correlation with another British cabinet of the same make, but of later and improved design using two blends of C.S.1663B type corrosion preventive oils, showed the same relative order but different absolute values.


VERY SEVERE CORROSION
SEVERE CORROSION
CONSIDERABLE CORROSION
MANY SPOTS
FEW SPOTS
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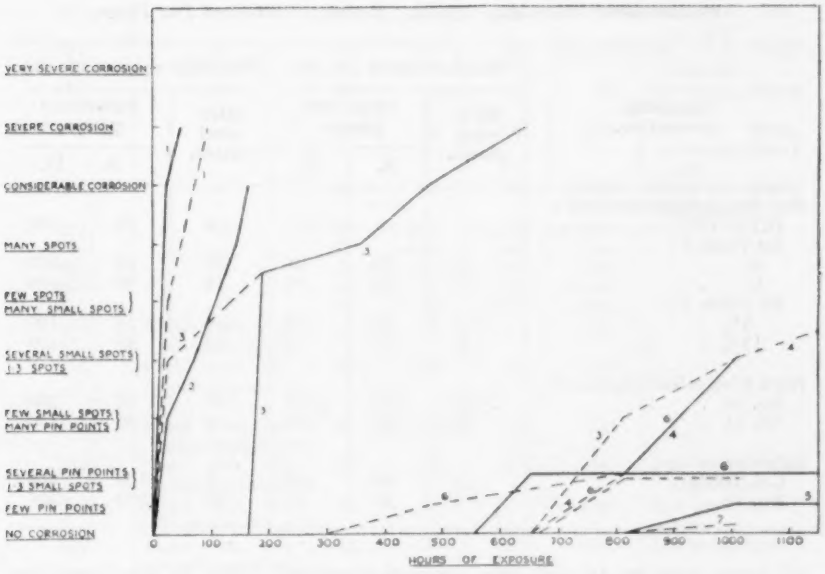
SEVERAL SMALL SPOTS
1-3 SPOTS
FEW SMALL SPOTS
MANY PIN POINTS
SEVERAL PIN POINTS
1-3 SMALL SPOTS
FEW PIN POINTS
NO CORROSION
0
100
200
300
400
500
600
700
800
900
1000
1100
HOURS OF EXPOSURE

FIG. 4.


VERY SEVERE CORROSION
SEVERE CORROSION
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MANY SPOTS
FEW SPOTS
MANY SMALL SPOTS
SEVERAL SMALL SPOTS
1-3 SPOTS
FEW SMALL SPOTS
MANY PIN POINTS
SEVERAL PIN POINTS
1-3 SMALL SPOTS
FEW PIN POINTS
NO CORROSION
0
100
200
300
400
500
600
700
800
900
1000
1100
HOURS OF EXPOSURE

FIG. 5.

TABLE X.

Humidity Cabinets. U.S./U.K. Correlation—Humidity Corrosion Preventives to Specification AN-VV-C576a.

Corrosion preventive code.	Life, hr.		
	U.S. Lab humidity, 95–100%.	U.K. Lab humidity.	
		95%.	100%.
R	100–150	100–150	100–200
S	175–225	100–400	50–100
T	350–400	>400	>400
U–(U.K. materials)	150	160	>400
U–(U.S. materials)	150	160	400

More rusting took place in twelve days in one cabinet than in ninety-five days in the other.

In the U.S./U.K. correlation tests no significant differences were shown when using different test plates. That the nature of the test plate can, however, affect the amount of protection is shown in Table XI, in which humidity cabinet and weatherometer results with emeried and Parkerized mild steel are shown.

Another interesting feature of Table XI is the long life shown by some

TABLE XI.

Weatherometer—Humidity Cabinet. Emeried, Parkerized Test Plates.

Corrosion preventive.	Weatherometer life, hr.			Humidity cabinet life, hr.		
	Mild-steel plates.	Parkerized plates.		Mild-steel plates.	Parkerized plates.	
		A.	D.		A.	D.
Soft film, solvent-deposited :						
D.T.D.121C	—	—	—	<4	20	100
Ex Table I :						
A	24	30	40	70	40	>400
C	10	20	40	10	20	>400
Ex Table V :						
5%	<1	10	20	<4	20	100
15%	24	30	40	70	40	>400
Hard film, solvent-deposited :						
No. 10	>126	300	>187	120	40	200
No. 11	50	250	150	6	40	150
Inhibited oil type :						
C.S. 1663F	<1	20	100	<4	100	>400
No. 12	<1	20	20	30	300	>400

oil types relative to soft-film, solvent-deposited types in the humidity cabinet but not in the weatherometer. The reverse order has been obtained on other occasions, and is more in line with general experience.

Taking all these experiences into consideration the general conclusion

was that this type of humidity cabinet was a less reliable instrument than the weatherometer, and its use was eventually abandoned. The use of the C.C.I. (Ministry of Supply) and the AN-H-31 cabinets with the same types of temporary corrosion preventives is now under investigation.

Relation Laboratory Tests/Atmospheric Exposure.

Prima facie, the conditions in the weatherometer are more comparable with outdoor exposure conditions and those in the humidity cabinet with the tropical extremes of indoor exposure. Temporary corrosion preventives are intended, in the main, for use in packaging and indoor storage,

Table XII.

Comparison Outdoor/Laboratory Exposures.

Blend.	Type.	Protective, %.	Outdoor, days.	Weatherometer, hr.	Cabinet hr.	Notes on outdoor test.
107	Soft film, solvent-deposited	15	21	18	300	
441	—	15	28	40	320	1st week, rain every day
448	—	15	42	280	500	2nd week, rainy periods
468	—	15	28	120	580	3rd week, fine, no rain
470	—	15	21	20	150/1500	4th week, fine, no rain
472	—	15	17	20	150/1500	5th week, daily showers
491	—	15	7	12	48	6th week, heavy rain
D.T.D.121D	—	35	70	180	650	7th week, showery/heavy rain
420	—	35	30	100	>1300	8th/10th week, showery
421	—	35	>105	400	>1300	
425	—	35	>105	400	>1300	
431	—	35	105	900	1000	
435	—	35	42	520	>2000	
436	—	35	42	>1000	>2000	
495	Hard film, solvent-deposited	42	35	42	144	
496	Hard film, solvent-deposited	42	40	80	144	
496	Hard film, solvent-deposited	42	21	90	144	
513	Hard film, solvent-deposited	42	28	165	>1000	1st week, fair, slight rain
515	Hard film, solvent-deposited	42	35	230	>1000	2nd week, heavy rain
520	Hard film, solvent-deposited	42	28	215	1000	3rd week, wet
534	Hard film, solvent-deposited	42	21	310	>1000	4th week, wet
421	Soft film, solvent-deposited	35	>35	325	>1000	5th week, wet

although they are often used, and successfully used, also under outdoor conditions. In view of the unreliability of the humidity cabinet results and the long test periods involved in indoor exposure tests, there are no data from the above-mentioned investigations which can be used to correlate indoor storage with laboratory tests.

In spite of variability of outdoor conditions, outdoor tests were more commonly performed, and Table XII shows the relation between such tests and the weatherometer and cabinet tests in two separate series of tests. There is obviously no precise quantitative relationship, but there is a general rough parallelism which has been useful in evaluating the respective merits of material and in giving confidence in selected formulations.

It must be stressed, however, that, in our experience, the weatherometer and the humidity cabinet can be used only as a qualitative means of comparison amongst similar types of materials tested simultaneously. It is not possible to give a fixed " Life Value " to a material nor to compare results from experiments made at different times.

Acknowledgments.

For the data presented in this paper, the author is indebted to several colleagues (especially V. W. David) who by patient endeavour succeeded in formulating temporary corrosion preventives in spite of the vagaries of test methods. Thanks are also due to the " Shell " Refining & Marketing Co. Ltd., for permission to publish.

A METHOD FOR THE EVALUATION OF SOFT-FILM TEMPORARY CORROSION PREVENTIVES FOR FERROUS ARTICLES.

By T. P. Hoar and G. C. Smith.

Synopsis.

A new technique for the assessment of soft-film temporary corrosion preventives is described. A very thin but reproducible film is deposited from a volatile solvent on to a clean steel surface, and the incidence of corrosion due to small drops of distilled water is determined after 24 hr.

The technique has been used to evaluate the relative protective value of several compositions of mineral jelly (specification C.S.1317) with amphipathic substances. The composition of three parts mineral jelly with one of lanolin (Anti-Corrosion Lubricant No. 2, specification C.S.1045) is shown to be a considerably better protective than the plain jelly, and to be further improved by the substitution of wool-grease for lanolin. The addition of 2% (solids) of sodium petroleum sulphonate to mineral jelly and to any of the above compositions greatly improves their protective value, and there are indications that considerably less sulphonate would still be effective. High-melting-point mineral jellies are somewhat more protective than plain mineral jelly, but petroleum sulphonate additions *impair* their performance.

The results are discussed in terms of the adsorption of a firmly held monolayer of amphipathic substance on the oxide-film surface of the metal.

Introduction.

The evaluation of soft-film temporary corrosion preventives has commonly been attempted by " accelerated " corrosion tests on metal specimens carry-

ing films of protective as thick as those aimed at in practice; intensification of the atmospheric attack against which such protectives are utilized has generally been obtained by the use of enhanced and varying temperature and humidity in a so-called "humidity cabinet." Such a procedure is a test of *a mechanically very good coating under very severe conditions.* In practice, however, soft-film protectives are apt, through uneven application and/or scratching, smearing, or rubbing, to have areas where the film is relatively poor, and it is at just these areas that corrosion begins, even when the corrosive conditions are relatively mild. Thus a more rational evaluation of such materials is obtainable by a test of *a mechanically poor coating under relatively moderate conditions.*

The technique described herein is an attempt to realize such a test in the simplest possible way. A thin, poor, but reproducible coating of the protective is applied to steel specimens from a dilute solution of the protective in a volatile, inert solvent. A number of small drops of distilled water are placed on the coated specimen, and the incidence of rusting after 24 hr is observed. By comparative experiments with several protectives carried out at the same time it is possible to obtain a clear differentiation between their efficiencies in semi-quantitative terms.

Experimental Technique.

Flat metal specimens about 4 × 5 cm, having a surface as free as possible from flaws, are degreased, and abraded uniformly with 1G emery. They are then again degreased with great care, using dried, re-distilled carbon tetrachloride, swabbed on with high-grade cotton wool, and finally with carbon tetrachloride applied with clean filter-paper. The specimens are afterwards handled only with tongs or with the fingers covered with filter-paper sheaths. They are stored in "dry" air in a calcium-chloride desiccator for a standard time, conveniently 24 hr, until required; this ensures that there is a reproducible invisible air-formed oxide-film on the specimens.

The prepared specimens are then transferred to an air-oven maintained at 110° C. There they are heated for 30 min to obtain surfaces that are as free as possible from adsorbed water, after which they are cooled in the desiccator. When cool, each specimen is transferred to a level plate-glass table, and all draughts in the neighbourhood of the specimen are excluded. Then, 1 ml of the appropriate solution of the protective (conveniently, 0·1 to 0·5 per cent in petroleum ether (40° to 60° C) or chloroform) is taken in a clean pipette and run on to the specimen, the pipette being held vertically over the centre of the specimen with its mouth about 0·5 cm above it. Surface tension prevents the solution from flowing over the edges of the specimen, and the ripples produced on the surface of the solution as it flows on to the specimen are seen to disappear, leaving a smooth liquid surface, before the solvent evaporates. When there is no further visible evaporation, the specimens are placed on a level table in an air-oven maintained at 90° C, and left for 15 min to complete the solvent evaporation and to enable the film of protective to interact with the oxide-film surface of the metal in a way similar to that obtaining in practice, where the metal parts are dipped in protective maintained at about 90° C. The specimens are cooled on a level glass plate protected from dust. Duplicate or triplicate specimens are prepared for each protective under test.

The specimens are transferred for test to a level glass support, which stands in a dish of water, and which can be covered with a large bell-jar, so that about 100 per cent relative humidity can be maintained over the specimens. Drops, about 0·05 ml, of the corrosive liquid (normally, distilled water) are placed on the specimens by means of a pipette, 10 drops to each specimen, the marginal portions being avoided. The whole apparatus is disposed in a room held at $25° \pm 0·3°$ C, and the number of drops showing rust after a given time, usually 24 hr, is observed. This time is not critical, since it is found that drops that are going to rust do so within the first few hours, any ensuing period up to several days resulting merely in the intensification of the rusting. The degree of spread of the drops over the surface is also observed, for this gives an indication of the water-emulsifying properties of the protective.

Reproducibility for duplicate or triplicate specimens in any one run is excellent, as will be seen from the results given later. Reproducibility from run to run is, however, rather uncertain, for reasons that have not yet been fully elucidated. In practice this is no great disadvantage, since sufficient specimens can be included in a run to provide a large number of comparative results.

Experimental Results.

The technique has been used to evaluate the relative efficiencies of two well-known soft-film protectives for ferrous articles, viz., mineral jelly (to specification C.S.1317) and Anti-Corrosion Lubricant No. 2 (to specification C.S.1045), which is a 75 : 25 mixture of mineral jelly and lanolin. The influence of additions of oil-soluble petroleum sulphonates to these basic protectives, the effect of the substitution of wool-grease for lanolin in Anti-Corrosion Lubricant No. 2, and the comparative efficiency of some high-melting-point mineral jellies, have also been studied. The solidification-points of all the materials were determined by the method given in the Appendix.

The metal used throughout the experiments was bright cold-rolled mild-steel strip of good surface, taken as typical in corrosion behaviour of many ferrous machine parts. Specimens of other materials, such as cast iron or alloy steels, could and should be used if their protection is being specifically considered.

Comparison of Basic Protectives and Influence of Petroleum Sulphonates.

Experiments were designed to show the difference, if any, between mineral jelly and Anti-Corrosion Lubricant No. 2, and also to show whether additions of sodium and calcium petroleum sulphonates have any inhibiting action. Sodium petroleum sulphonate was added as a 40 per cent solution in oil, calcium petroleum sulphonate as a 25 per cent solution in oil, in quantities to give 2 per cent (solids) of each sulphonate in the final mixture. It is realized that this would be a high upper limit in practice, but it was chosen so that any inhibiting effect might quickly be recognized.

The standard routine outlined above was followed, the corrosive agent being distilled water. The results are summarized in Table I.

The superiority of Anti-Corrosion Lubricant No. 2 over mineral jelly is very clearly indicated. Both the petroleum sulphonates are seen to have

TABLE I.

Comparison of Basic Protectives and Influence of Petroleum Sulphonate Additions.

Specimens: Cold-rolled steel strip, 4 × 5 cm, ground 1G emery, stored 3 hr in dry air, dried at 110° C. Duplicates.
Protectives applied from 0·33 per cent and 0·1 per cent solutions in 40° to 60° C petroleum ether, 1 ml solution per 20 cm², heated (after evaporation) for 15 min at 90° C.
Corrosive liquid: Distilled water, 10 drops each about 0·05 ml; 24 hr, 25° C.

Protective.			0·33% solution.			0·1% solution.		
Major constituent.	Minor constituent.	S.P.,* ° C.	Drops rusting.	Fig. of merit.†	Spread.‡	Drops rusting.	Fig. of merit.†	Spread.‡
Mineral jelly, C.S.1317B	Nil	49	8 sl.; 9 sl.	58	0	10; 10	0	0
	2% (solids) sodium petroleum sulphonate	48	1 sl.; 0	98	3	10; 9	3	1
	2% (solids) calcium petroleum sulphonate	48	2 sl.; 3 sl.	88	6	10; 8, 2 sl.	5	1
Anti-corrosion lubricant No. 2	Nil	47	0; 0	100	1	10; 10	0	0
	2% (solids) sodium petroleum sulphonate	46	0; 0	100	6	2 v. sl.; 1 v. sl.	97	2
	2% (solids) calcium petroleum sulphonate	46	0; 0	100	4	0; 0	100	3

* Solidification point; see Appendix.
† The Figure of Merit is calculated as follows: From a possible 100 marks indicating no rusting, deduct 10 for each drop rusting fully, 5 for each rusting slightly over less than ¼ of its area, 2 for each showing very slight rust, and take the mean for duplicate specimens.
‡ The numbers 0 . . . 6 indicate No spreading of drops . . . Heavy spreading.

marked inhibitive properties, providing improvement in both the basic protectives, although the improvement effected in mineral jelly by 2 per cent of sulphonate is less than that effected by converting it into Anti-Corrosion Lubricant No. 2 by adding one part of lanolin to every three of jelly—as might indeed be expected. There is little to choose between the sodium and calcium sulphonates.

A drawback to using 2 per cent of the sulphonates in mineral jelly or in Anti-Corrosion Lubricant No. 2 is that the spread of the water drops over the surface of the protective is rather extensive, indicating a tendency to emulsification either of water into the film or of the film into water. This spread can be reduced by reducing the concentration of the inhibitor in the protective, which scarcely impairs the efficiency of film. The lower limit of sulphonate concentration, where good corrosion-inhibiting properties are still to be found, has not been completely elucidated, but preliminary experiments indicate that it may be as low as 0·1 per cent of inhibitor. Evidently the ideal concentration of inhibitor is that which will form an oriented monolayer at the oxide-film surface, while leaving very little inhibitor in the bulk of the film of protective, so that there is no tendency for water to emulsify into it, or for the film to emulsify into water; obviously this ideal requires that the inhibitor should be very strongly adsorbed at the oxide-film surface.

Substitution of Wool-Grease for Lanolin.

Experiments were carried out to determine the effect of substitution of wool-grease for lanolin in Anti-Corrosion Lubricant No. 2. Two commercial brands of wool-grease, and a sample of commercial anhydrous lanolin,

were blended in the laboratory with a standard mineral jelly sample; a commercially blended sample of Anti-Corrosion Lubricant No. 2 was included in the run. The influence of a 2 per cent (solids) addition of sodium petroleum sulphonate on each composition was also studied.

Table II shows comparisons of these compositions, tested as very thin

TABLE II.

Comparison of Plain Mineral Jelly with Various Wool-grease and Lanolin Mixtures.

Specimens: Cold-rolled steel strip, 4 × 5 cm, ground 1G emery, stored 24 hr in dry air dried at 110° C. Duplicates.
Protectives applied from 0·1 per cent solution in chloroform, 1 ml solution per 20 cm², heated (after evaporation) for 15 min at 90° C.
Corrosive liquid: Distilled water, 10 drops each about 0·05 ml; 24 hr, 25° C.

Protective.		S.P., °C.	Drops rusting.	Fig. of merit.	Spread.
Major constituents.	Minor constituent.				
Mineral jelly, C.S.1317B	Nil	49	10; 10	0	0
	2% (solids) sodium petroleum sulphonate	48	8, 2 sl.; 7, 3 sl.	12	2
Mineral jelly 75%, anhydrous lanolin 25%	Nil	46	10; 10	0	1
	2% (solids) sodium petroleum sulphonate	45	8, 1 v. sl.; 8, 1 sl., 1 v. sl.	15	3
Mineral jelly 75%, wool-grease "A" 25%	Nil	46	5, 4 sl.; 8, 8, 2 v. sl.	23	1
	2% (solids) sodium petroleum sulphonate	45	4, 1 sl., 4 v. sl.; 5, 4 v. sl.	44	3
Mineral jelly 75%, wool-grease "B" 25%	Nil	46	9, 1 sl.; 6, 3 sl., 1 v. sl.	15	1
	2% (solids) sodium petroleum sulphonate	45	6, 3 sl.; 4, 2 sl.	40	4
Anti-corrosion lubricant No. 2	Nil	47	10; 9, 1 sl.	3	1
	2% (solids) sodium petroleum sulphonate	46	9; 9	10	2

films spread from 0·1 per cent solutions in chloroform. It will be noted that both wool-grease compositions compare favourably in protective value with both lanolin compositions. In all cases there is a similar slight lowering of solidification-point as compared with plain mineral jelly. In all cases also the addition of 2 per cent (solids) of sodium petroleum sulphonate leads to a further improvement, though lowering the solidification-point a further 1° C.

Table III shows comparisons of the same compositions tested by exposure of coated specimens to the atmosphere on the laboratory roof. These specimens were given a much thicker coat, from 5·0 per cent solutions of the compositions in chloroform, and the bulk of this coating was then

deliberately rubbed off in as reproducible a manner as possible, in an attempt to simulate practical conditions of chafing. Again, the wool-

TABLE III.

Outdoor Exposure Tests on Rubbed Specimens.

Specimens : Cold-rolled steel strip, 4 × 5 cm, ground 1G emery, stored 24 hr in dry air, dried at 110° C. Duplicates.
Protectives applied from 5 per cent solution in chloroform, 1 ml solution per 20 cm^2, heated (after evaporation) for 15 min at 90° C.
Rubbing : Specimens cooled and then protective-covered side rubbed on a filter-paper pad twelve times, in each of two directions at right angles.
Exposure : Atmospheric. Wind and rain.

Protective.		S.P., °C.	Corrosion * after :	
Major constituents.	Minor constituent.		1 day.	3 days.
Mineral jelly, C.S.1317B	Nil	49	5, 5	6+, 6+
	2·0% (solids) sodium petroleum sulphonate	48	4, 4	6, 6
Mineral jelly 75%, anhydrous lanolin 25%	Nil	46	6, 6	6+, 6+
	2·0% (solids) sodium petroleum sulphonate	45	3, 3	5, 4
Mineral jelly 75%, wool-grease "A" 25%	Nil	46	0, 0	2, 2
	2·0% (solids) sodium petroleum sulphonate	45	0, 0	2, 2
Mineral jelly 75%, wool-grease "B" 25%	Nil	46	4, 4	6, 5
	2·0% (solids) sodium petroleum sulphonate	45	1, 1	4, 4
Anti-corrosion lubricant No. 2	Nil	47	5, 5	6+, 6+
	2·0% (solids) sodium petroleum sulphonate	46	5, 5	6, 6

* The numbers 0 . . . 6 indicate No Rust . . . Heavy Rusting.

grease compositions compare favourably with the lanolin, and even under these conditions of severe rubbing, sodium petroleum sulphonate still has some beneficial influence.

High-melting-point Mineral Jellies.

Two high-melting-point (HMP) mineral jellies were compared with ordinary mineral jelly, (*a*) uncompounded, (*b*) as 75 : 25 mixtures with wool-grease "B," and (*c*) with addition of 2 per cent (solids) of sodium petroleum sulphonate.

The results of three separate experimental runs are given in Tables IV to VI; the good reproducibility of duplicate specimens within a run, and the relatively poor reproducibility between runs referred to above, is exemplified in these tables. It will be seen that the following conclusions can be drawn :—

(i) In the uncompounded state, the HMP jellies are rather better than the ordinary (Tables IV and V).

(ii) In the 75 : 25 mixtures, with wool-grease "B," HMP jelly "Y" is rather better, HMP jelly "X" about the same, as the ordinary

TABLE IV.

Comparison of Ordinary and High-melting-point Mineral Jellies, Uncompounded and as 75/25 Mixtures with Wool-grease.

Specimens: Cold-rolled steel strip, 4 × 5 cm, ground 1G emery, stored 24 hr in dry air, dried at 110° C. Duplicates.
Protectives: Applied from 0·1 per cent and 0·33 per cent solutions in chloroform, 1 ml solution per 20 cm², heated (after evaporation) for 15 min at 90° C.
Corrosive liquid: Distilled water, 10 drops each about 0·05 ml; 24 hr, 25° C.

Protective.	S.P., ° C.	0·1% solution.			0·33% solution.		
		Drops rusting.	Fig. of merit.	Spread.	Drops rusting.	Fig. of merit.	Spread.
Mineral jelly, C.S.1317B	49	10; 6, 3 sl.	13	0	8; 8, 2 sl.	18	0
Mineral jelly, 75%, wool-grease "B" 25%	46	3, 2 sl.; 1, 2 sl., 2 v. sl.	68	1	1, 4 sl.; 0	85	1
HMP jelly "X"	60	2, 3 sl.; 6 sl.	68	0	1, 1 sl.; 2 v. sl.	91	0
HMP jelly "X" 75%, wool-grease "B" 25%	59	3, 2 sl., 1 v. sl.; 4, 2 sl.	54	1	2 v. sl.; 3 v. sl.	95	1
HMP jelly "Y"	67	8 sl.; 8 sl.	60	0	1 v. sl.; 0	99	0
HMP jelly "Y" 75%, wool-grease "B" 25%	65	2, 2 sl., 1 v. sl.; 2, 2 sl.	69	1	0; 0	100	1

TABLE V.

Comparison of Ordinary and High-melting-point Mineral Jellies, Uncompounded, and with Addition of 2% (Solids) of Sodium Petroleum Sulphonate.

Conditions as in Table IV, but only 0·1 per cent solutions used.

Protective.		S.P., ° C.	Drops rusting.	Fig. of merit.	Spread.
Major constituent.	Minor constituent.				
Mineral jelly, C.S.1317B	Nil	49	2, 1 sl., 1 v. sl.; 1, 3 v. sl.	77	1
	2% (solids) sodium petroleum sulphonate	48	0; 0	100	2
HMP jelly "X"	Nil	60	1 v. sl.; 0	99	0
	2% (solids) sodium petroleum sulphonate	59	1, 3 sl., 1 v. sl.; 1 v. sl.	86	0
HMP jelly "Y"	Nil	67	1, 1 sl., 1 v. sl.; 1 sl., 3 v. sl.	85	0
	2% (solids) sodium petroleum sulphonate	66	2, 1 sl., 3 v. sl.; 1, 1 v. sl.	79	0

TABLE VI.

Comparison of Ordinary and High-melting-point Mineral Jellies, with 2% (Solids) of Sodium Petroleum Sulphonates.

Conditions as in Table IV.

Protective.	S.P., °C.	0·1% solution.			0·33% solution.		
		Drops rusting.	Fig. of merit.	Spread.	Drops rusting.	Fig. of merit.	Spread.
Mineral jelly, C.S.1317B, 2% (solids) sodium petroleum sulphonate	48	1 sl.; 1 sl.	95	1	0; 0	100	3
HMP jelly "X," 2% (solids) sodium petroleum sulphonate	59	1, 4 sl.; 1 sl., 1 v. sl.	82	0	1 sl.; 0	98	1
HMP jelly "Y," 2% (solids) sodium petroleum sulphonate	66	2, 8 v. sl.; 1, 9 v. sl.	68	0	3 sl., 6 v. sl.; 2 sl., 5 v. sl.	77	0

jelly. Compounding with wool-grease lowers the solidification-points slightly in all cases (Table IV).

(iii) With sulphonate additions, the HMP jellies are less protective than ordinary mineral jelly with sulphonate (Table VI). Indeed, far from having inhibitive value in the HMP jellies, sulphonate actually reduces their protective action (Table V).

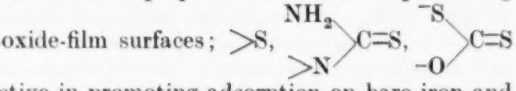
It should be remembered that all the above results refer to tests at 25° C. It is quite possible that the HMP jellies would show to better advantage if tested as protectives at a higher temperature.

DISCUSSION.

The rapidity of the present testing technique—results are obtained in 24 hr—is a great convenience, but may lead to the impression that the technique is an "accelerated test" of which the comparative results given by different protective compositions can bear little relation to those that would occur in practice. In fact, the test is not an accelerated test in the usual sense of the term—rusting when it sets in probably proceeds at much the same rate as it would in practice: but the test provides a rapid answer to the question: "What will happen at thin, imperfect places of a practical protective coating, if and when a drop of condensed water appears thereon?", and we believe that the practical efficiency of soft-film protectives may be very well assessed on such a basis.

Although, as pointed out above, the imperfect reproducibility of the test results as between different experimental runs is of no great significance in the comparison of protectives—for the order of efficiency of several protectives included in any one run is always the same—it is obvious that the

causes for the imperfect reproducibility have considerable theoretical and practical interest. Preliminary experiments, in which the time during which the prepared specimens were exposed to " dry " air (in a calcium-chloride desiccator) and the time of heat treatment of the coated specimen were separately varied, showed that neither of these times is critical; the values of 24 hr and 15 min finally adopted can be considerably varied without influencing the results. Furthermore, experiments in which the specimens were allowed to stand for 2·5 hr in moist air (over saturated zinc sulphate solution at 25° C) before application of the protective gave results showing only very slightly inferior protection to that obtained with " dry " specimens. The influence of the temperature and relative humidity of the atmosphere during the actual application of the protective, after the desiccator storage, has not yet been studied; if the attainment of adsorption equilibrium of water molecules on the prepared specimens is a fairly rapid process, the temperature and humidity of the general atmosphere may be more important than that of any desiccator atmospheres to which the specimens are previously deliberately exposed. Further work on these lines is evidently desirable.

With regard to the results obtained in the present work for different protective compositions, one feature is of paramount interest; the nearly non-polar mineral jelly is always improved as a protective by the addition of an amphipathic substance containing a polar group or groups in a basically " oily " molecule, such as lanolin, wool-grease, and the petroleum sulphonates. It is highly probable that such molecules act by becoming strongly adsorbed through their polar groups on the oxide-film surface of the metal; they thus form a firmly held basis, much more difficult for water to displace than adsorbed hydrocarbon molecules, for the purely " oily " molecules in the protective. There are doubtless very many other amphipathic substances that would be at least as effective as those tried—on the practical grounds of ready supply and cheapness—in the present work. It is likely, from general considerations based on experience in temporary protectives, slushing oils, cutting emulsions, paints, and other environments that assist oxide-film-covered ferrous materials to resist the onset of corrosion, that the groups $-SO_3H$, $-CO_2H$, $-OH$, and perhaps $-NH_2$, are the most effective polar constituents of amphipathic molecules in promoting strong adsorption on iron-oxide-film surfaces;  , and related groups, so effective in promoting adsorption on bare iron and on sulphide surfaces—as shown by the extensive use of amphipathic substances containing them as inhibitors in ferrous pickling and as collectors in sulphide ore flotation—are relatively ineffective for promoting adsorption on oxide surfaces.

The somewhat erratic behaviour of the two high-melting-point mineral jellies tested—good performance of the plain jellies compared with plain ordinary jelly, but relatively poor performance when compounded with petroleum sulphonate—is not entirely unexpected. The stiffer materials may well give a mechanically better film (though even this is doubtful, in the case of HMP jellies containing much wax, which tends to produce shrinkage), but it is quite likely that ordinary jelly of lower viscosity pro-

vides a vehicle from which adsorption of amphipathic material on to the oxide-film surface can the more readily and rapidly occur.

ACKNOWLEDGMENTS.

This work was carried out in 1944–45 for the Ministry of Supply. We acknowledge with many thanks the permission of the Chief Scientist to publish the present account.

Department of Metallurgy,
University of Cambridge,
January 3, 1950.

APPENDIX.

Determination of Solidification Point of Soft-film Temporary Protectives.

About 20 g of the protective is melted in a 100-ml beaker. A ¼-in dia steel ball-bearing (weight about 1 g) is placed in the melt, and the whole allowed to cool while being continuously stirred with a thermometer. The solidification point is taken as the temperature below which the ball bearing is unable to roll along the bottom of the beaker under its own weight, when the beaker rests on an inclined sheet of glass making an angle of 23° with the horizontal. Observation is by means of a mirror placed below the inclined glass sheet. The results are reproducible to within 0·5° C, and while in no sense absolute, give a reliable relative indication of the differences in solidification point for a series of protectives.

APPLICATION OF AN ACCELERATED ATMOSPHERIC CORROSION TEST TO THE ASSESSMENT OF TEMPORARY CORROSION PREVENTIVES.

By R. ST. J. PRESTON * and E. G. STROUD.*

SUMMARY.

An accelerated atmospheric corrosion test, in which specimens are exposed in a thermostatically controlled humid atmosphere containing sulphur dioxide, has been applied in the assessment of temporary corrosion preventives. The protectives included materials ranging from light lubricating oil, through petroleum jelly, to bitumen.

The average order of failure of steel panels coated with the protectives, exposed in various parts of the U.K. in unheated sheds, approximated to that obtained in the laboratory test of one weeks' duration.

A plain humid atmosphere was insufficiently aggressive to break down most of the samples, in spite of a prolonged period of test.

IN recent years there has been an increasing use of temporary protectives on metal in the interim stages of fabrication or on metal parts in store. As their name indicates, temporary protectives are intended for relatively short-time protection only, and are characterized by ease of removal when the article is required for use. It should be emphasized that the whole burden of protection in all circumstances cannot be delegated in practice to a comparatively thin film of readily removable material, irrespective of

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other conditions, such as severity of the atmosphere and time of exposure. It is possible, however, to define within limits the conditions which a protective is required to withstand, and with this knowledge a choice of suitable materials can be made. These conditions may vary from a clean, equable atmosphere to an open situation in an industrial area, protected only from direct rain. Practical experience associated often with laboratory or accelerated tests has enabled the majority of protectives to be graded for their particular purpose. Experience, however, is an expensive teacher, and although it must always remain the final arbiter, a laboratory test that could guide the choice of protective, or at least evaluate with some accuracy the worth of existing and new protectives, is very desirable.

A good deal of the onus of testing protectives has been laid on the well-known humidity test, many different and elaborate types of which have been designed. It is understood that such tests are not regarded highly by some, mainly because of the difficulty in evaluating the more durable types. Moreover, these difficulties cannot be overcome by prolonging the time of test, and it may be deduced that the conditions of a humidity test are neither severe enough nor closely enough related to usual conditions of exposure to be of practical value. In unsaturated atmospheres Vernon * has shown that the influence of impurities normally present in the atmosphere is intimately associated with that of relative humidity, a critical value of which must be exceeded before severe corrosion occurs; on the other hand, there is virtually no attack in the absence of such impurities. Substances mainly responsible for corrosion under the conditions stated include sulphur dioxide and dispersed solid particles which act as nuclei for rust formation. Similar forms of curves (corrosion *v.* humidity *v.* pollution) were obtained for gaseous and solid pollution, and the two effects were shown to be additive. Substances of the types mentioned may, therefore, be used to accelerate the action of a humidity test. Chloride salts are commonly used in the well-known salt-spray tests, representing the second type of accelerator mentioned, but a closer relation with normal atmosphere, in which temporary protectives are used, is obtained by the use of sulphur dioxide, with or without the addition of nuclei.

It should be emphasized that the present work is concerned entirely with conditions of "super-saturation" such that moisture is intermittently precipitated on the specimen. Under such conditions, the use of small concentrations of sulphur dioxide alone gives adequate acceleration.

The use of sulphur dioxide has received surprisingly little attention in testing techniques, and it was therefore considered worth while applying this type of test to a range of temporary protectives which had been provided by the Protectives Panel of the Institute of Petroleum. (See Table I.) The objectives of this Panel include the assessment of protectives by means of exposure tests in different parts of the U.K. and the development of a laboratory test.

A test employing a humid atmosphere containing a small amount of sulphur dioxide has been in use at the Chemical Research Laboratory for some time and was, therefore, available for application to the series of temporary corrosion preventives.

* *Trans. Faraday Soc.*, 1935, **31**, 1678–98.

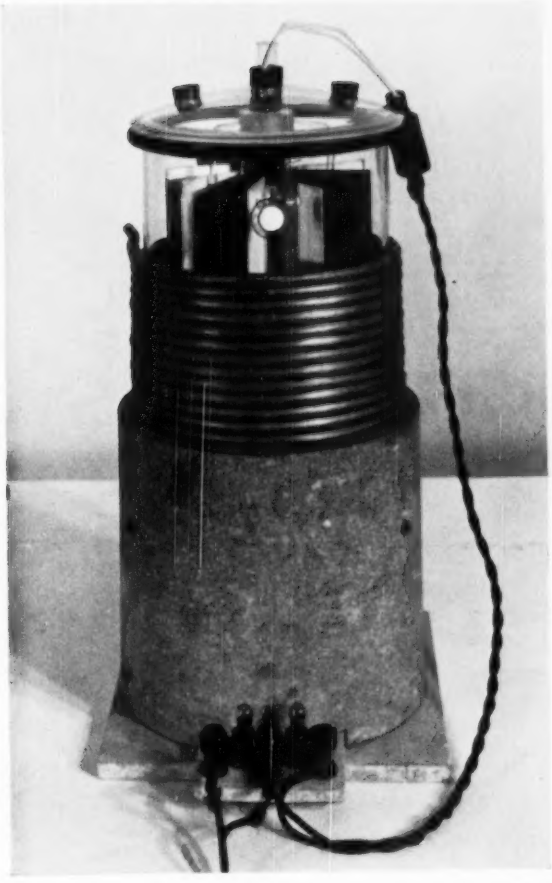
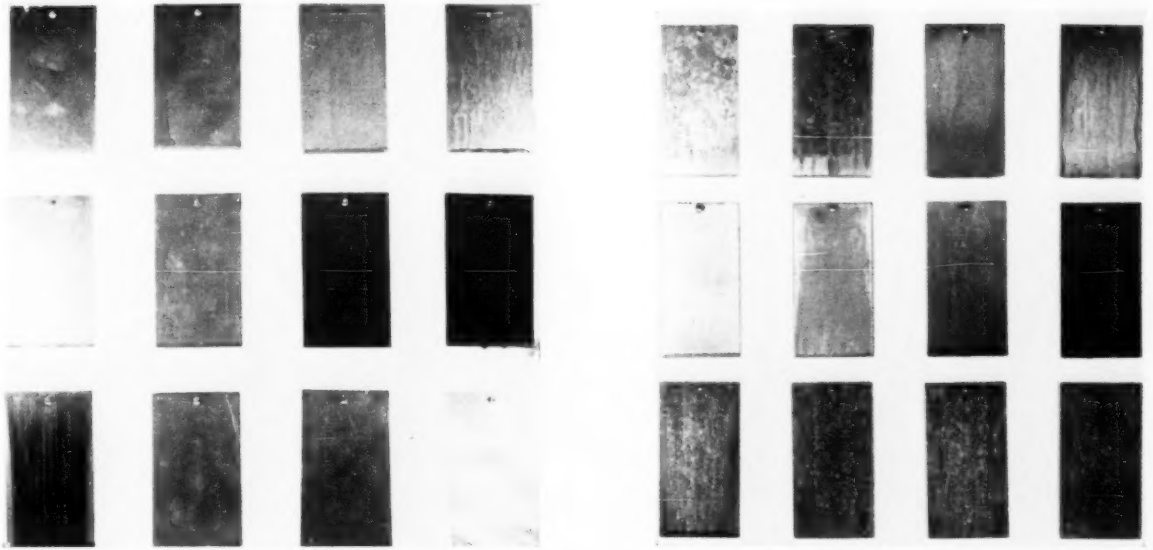


FIG. 1.

ACCELERATED CORROSION TESTING APPARATUS

[*To face p.* 158.



Panels coated with protective. Coated panels after test.

Code for protectives (see Table 1).

1	2	3	4
5	6	7	8
9	10	11	Blank

FIG. 2.

COATED PANELS BEFORE, AND AFTER, TESTING IN A MOIST ATMOSPHERE CONTAINING SO_2.

Description of Laboratory Test.

The C.R.L. simplified accelerated atmospheric corrosion test apparatus (see Fig. 1) consists of a large beaker containing a small volume of water (500 ml), the lower part of the beaker being heated to a temperature controlled by a thermostat; the upper part is cooled, thus ensuring a supersaturated atmosphere. The specimens are suspended from a dished Perspex lid. A small volume of aqueous sulphur dioxide solution is added periodically, but otherwise the apparatus requires no attention.

The performance of the protectives was assessed by two methods, the first of which was used by the Panel for the field tests, viz.: (i) Initial time to the appearance of an average of one spot of rust per square inch of surface area, excluding the peripheral $\frac{1}{4}$ in, *i.e.*, eighteen spots per side of dimensions 6 in × 3 in; (ii) loss in weight of metal after removing the protectives and de-rusting in inhibited acid.

Steel sheets (20 gauge) to specification B.S. 970 EN2A/1 and size 6 in × 3 in were used in the laboratory test (6 in × 4 in in the field test), the surface being prepared by the method recommended by the Panel. The specimens were abraded with No. 0 emery cloth, finishing with a circular motion, de-greasing by immersion in sulphur-free toluene, swabbed with cotton wool followed by a dip in methyl alcohol, and dried in a stream of warm air. The panels were weighed and the protectives applied by the method drawn up by the Panel for the field tests (see Table I). The weight of protective on each panel was found by re-weighing 24 hr after application.

Four conditions of test were used :—

(*a*) supersaturated atmosphere with no additions;

(*b*) supersaturated atmosphere with 5 ml of a standard solution of SO_2 added each working day at 9.15 a.m. and 5.15 p.m. (12 noon on Saturdays) (this was equivalent to 0·025 g or 0·005 per cent by wt of SO_2 in the liquid in the beaker);

(*c*) as (*b*) but SO_2 solution at double the strength previously used (*i.e.*, 0·05 g or 0·01 per cent by wt of SO_2 in the liquid);

(*d*) as (*c*) but the panels after coating and weighing were sprayed with a 10 per cent solution of ammonium sulphate to form nuclei on drying.

The duration of test (*a*) was nine weeks, that of (*b*), (*c*), and (*d*) one week. Uniform conditions were used for all tests, the thermostat being set to control the temperature of the water in the beaker at 48° C; the resulting temperature in the vapour was approximately 36° C.

Materials Examined.

Particulars of the protectives and the amounts applied are given in Table I.

Some variation in the weight deposited occurs for some of the protectives, owing to their accumulation at the lower edge on draining.

Field-exposure tests undertaken by individual members of the Panel at various stations are not yet completed, and the number of failed panels

TABLE I.

No.	Protective.	Method of application.	Wt of protective on specimen in g in tests :			
			(*a*).	(*b*).	(*c*).	(*d*).
1	D.T.D.121D. (35% lanolin in white spirit)	Cold dip at room temp for 5 sec, withdraw over 3 sec	0·13	0·14	0·13	0·12
2	D.T.D.121D diluted to 10% solids	As 1	0·04	0·04	0·04	0·03
3	Petrolatum	Temp of 165° F. Immerse for 90 sec and withdraw over 15 sec	1·93	2·30	2·06	1·91
4	Petrolatum + 2% glyceryl mono-oleate	As 3	2·57	2·76	2·89	2·28
5	No. 3, 21 pts/wt, toluene 79 pts/wt	At room temp, dip for 5 sec, withdraw in 3 sec. After 30 min place in room at 95° C for 4 min; then cool	0·95	0·94	0·68	0·77
6	No. 4, 21 pts, toluene 79 pts		1·26	1·03	0·78	0·88
7	C.S.1033B*	As 1	0·36	0·46	0·41	0·36
8	C.S.1033D†	As 1	0·48	0·65	0·50	0·46
9	C.S.1033D 100 pts, thinners 250 pts	As 1	0·05	0·07	0·06	0·05
10	C.S. 1663C‡	As 1	0·25	0·20	0·29	0·29
11	C.S.1663F§	As 1	0·22	0·29	0·22	0·26

* As 1033D, but probably improved bitumen.

† Oxidized bitumen, 18 parts ; hard neutral wool grease, 12 parts ; coal tar naphtha, 19 parts; trichlorethylene, 51 parts.

‡ Light mineral lub oil with lanolin or petroleum sulphonate inhibitor.

§ Light mineral lub oil (100 cs at 70° F), 80 parts ; lanolin, 15 parts ; kerosin, 5 parts.

varies from station to station; it has been possible, however, to draw up an average interim order of merit for the series of protectives by using the time to breakdown or alternatively partial breakdown as the criterion. Thus, three protectives showing on a 6 in × 4 in panel, (*a*) ten spots of rust at twenty-four days, (*b*) breakdown (twenty-four spots on one side) at six days, and (*c*) breakdown at twenty-one days would have a decreasing order of merit (*a*), (*c*), and (*b*). On this basis the order of merit for the field-exposure specimens is as given in Table II.

TABLE II.

Interim Order of Merit of Temporary Protectives in Field Tests.

Order of merit.	Protective.
1	C.S.1033D
2	C.S.1033B
3	Petrolatum
4	Petrolatum + 2% glyceryl mono-oleate, dilute
5	Petrolatum + 2% glyceryl mono-oleate
6	Petrolatum, dilute C.S.1033D, dilute
8	D.T.D. 121D
9	C.S.1663F
10	C.S.1663C
11	D.T.D.121D, dilute

Untreated specimens exposed at Teddington under sheltered outdoor conditions show a higher weight loss after de-rusting than those at other stations. This may be explained by the wide range of variation of atmospheric conditions observed at the Teddington exposure site, which is at ground level; both temperature and humidity vary over a wide range, and night mists are numerous during autumn and winter. Relative humidity readings taken at 9 a.m. during September, October, and November were 81, 93, and 91 per cent respectively; at 5.30 p.m. they were 67, 82, and 91 per cent respectively.

Results of Laboratory Tests.

The times to failure as determined by the appearance of rust spots and by the losses in weight at the end of the test are given in Table III.

Where a material has not reached the specified standard of failure (eighteen spots of rust per side of a 6 in × 3 in panel) before the test was brought to conclusion, the number of rust spots at the conclusion of the test is entered in brackets in Table III.

Table III.

Observations and Losses in Weight in Laboratory Tests.

	Days to failure.				Losses in weight, g			
	Test.				Test.			
	(*a*).	(*b*).	(*c*).	(*d*).	(*a*).	(*b*).	(*c*).	(*d*).
Time of test days :	63.	7.	7.	7.	63.	7.	7.	7.
D.T.D.121D	(3)	5	2	1	0·015	0·043	0·129	1·101
D.T.D.121D, dilute	(5)	1	1	1	0·036	0·631	2·510	3·118
Petrolatum	—	5	—	(10)	0·031	0·060	0·124	0·065
Petrolatum + 2% G.M.O.	(3)	3	2	2	0·015	0·085	0·159	0·138
Petrolatum, dilute	(11)	4	—	(16)	0·039	0·063	0·178	0·120
Petrolatum + 2% G.M.O. dilute	—	(4)	(5)	(4)	0·014	0·020	0·125	0·075
C.S.1033B	51	4	4	4	0·046	0·042	0·103	0·212
C.S.1033D	(2)	6	—	7	0·021	0·036	0·077	0·135
C.S.1033D, dilute	46	1	1	1	0·050	0·416	0·889	1·729
C.S.1663C	31	1	1	1	0·139	0·934	2·339	0·806
C.S.1663F	38	1	1	1	0·082	0·473	1·676	1·132
"Blank"—no coating	—	—	—	—	0·845	0·636	1·485	1·765

Orders of merit of the protectives, estimated from weight losses, determined in the four tests are given in Table IV, together with the average interim order for the field tests.

In Table IV, the bottom row gives the correlation coefficient between the order of merit of the laboratory and field tests; this coefficient is calculated by the "Spearman Ranking Method," in which the coefficient is calculated from the formula

$$\text{S.R.C.} = 1 - \frac{6 \times \Sigma d_1^2 d_2^2 d_3^2 \ . \ . \ . \ d_n^2}{n(n^2 - 1)}$$

d_1, d_2, etc., represent the arithmetic difference between the two ranks to

TABLE IV.

Orders of Merit of Laboratory Tests in Comparison with Outdoor Exposure Tests.

Protective.	Order of merit in tests :				
	Field.*	(*a*).	(*b*).	(*c*).	(*d*).
D.T.D.121D	8	2=	4	5	6
D.T.D.121D, dilute	11	6	10	11	11
Petrolatum	3	5	5	3=	1
Petrolatum + 2% G.M.O.	6=	2=	7	6	5
Petrolatum, dilute	5	7	6	7	3
Petrolatum + 2% G.M.O. dilute	4	1	1	3=	2
C.S.1033B	2	8	3	2	6
C.S.1033D	1	4	2	1	4
C.S.1033D, dilute	6=	9	8	8	10
C.S.1663C	10	11	11	10	7
C.S.1663F	9	10	9	9	9
Correlation coefficient with field tests	—	0·32	0·82	0·92	0·71

* Average interim order after approximately three months' exposure.

be compared with n the number of ranks. The nearer the coefficient approaches to unity, the better the correlation.

GENERAL OBSERVATIONS.

There was a tendency for protectives to be thicker on the lower parts owing to drainage.

Results in Table III confirm the view expressed earlier that a humid atmosphere alone is not sufficiently aggressive to yield a result in a reasonable time; only the weakest protectives fail, and even an approximate estimate of the values of moderate and good protectives is unattainable. With the addition of small amounts of SO_2 (0·025 g twice daily to the liquid in the beaker), see Test (*b*), a decided acceleration is achieved and the Spearman Ranking Coefficient increases from 0·32 to 0·82. The addition of 0·05 g SO_2 twice daily to the beaker shows further improvement and the coefficient becomes 0·92.

The application to the surfaces of the protectives of particles of ammonium sulphate by spraying on a 10 per cent solution does not improve the behaviour in the beaker test, a correlation between the orders of merit of 0·71 being obtained.

Photographs of treated specimens before, and after exposure to the stronger SO_2 atmosphere are shown in Fig. 2.

CONCLUSIONS.

A simplified accelerated atmospheric corrosion test apparatus in which specimens are exposed to a supersaturated atmosphere containing sulphur dioxide, appears to be a useful tool in the evaluation of temporary protectives. Absence of sulphur dioxide, the conditions applying in most humidity cabinets, is unsatisfactory, as the period of test is too long and all except the poorest of protectives fail to break down.

With sulphur dioxide present, exposure for one week gives good agree-

ment with the interim order of merit obtained for sheltered outdoor conditions.

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The work described above has been carried out as part of the research programme of the Chemical Research Laboratory, and this paper is published by permission of the Director.

TESTS OF THE PROTECTIVE VALUE OF TEMPORARY CORROSION PREVENTIVES ON STEEL.

By S. G. CLARKE * and E. E. LONGHURST *.

SUMMARY.

Results are presented on corrosion tests carried out by relatively simple methods. Free exposure to the outdoor atmosphere, the A.R.E. salt-spray test and a non-streaming humidity test gave comparable orders of merit for several protectives on steel. Outdoor exposure is generally too severe and variable for testing oil films. A sprayed-on water-droplet test discriminated between oil films. Increasing protection with rising film weight of lanolin was demonstrated in an outdoor test. A marked reduction in the weight of steel corroded in the A.R.E. salt-spray test was produced by extremely thin oil films.

INTRODUCTION.

VARIOUS methods of corrosion testing are in use by the authors in work on corrosion and protection of metals. From time to time certain of these methods have been employed in comparing the protective value of oils, greases, and other temporary protectives, and this paper gives results obtained by selected methods as follows :—

Tests employed.	Protectives tested (see Appendix for description).
Outdoor exposure	Oils, lanolin, other protectives
Water droplet	Oils only
Humidity (water condensation)	Lanolin, other protectives
Salt spray	Oils, lanolin, other protectives.

In order to promote valid comparison of the protectives, attention was paid in the course of the work to such factors as the uniformity of the steel surface in sets of specimens and to the film weight of the coating.

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Test Specimens.

General Remarks on Suitable Steel Specimens, and Their Preparation.

An important criterion in tests on these coatings is the stage of the commencement of rusting. In so far as susceptibility to commence rusting may originate in features of the steel surface itself—roughness or outcropping of inclusions or micro-constituents—it is desirable that the steel specimens for test should all be prepared in the same manner from similar steel. Thus specimens produced by machining from plate or bar should be suitable. For convenience in supply, test specimens of rolled steel of relatively thin section are often used by workers in this field. The bulk of such steel is of the " rimming " or " rising " variety having a thin skin of relatively pure iron originating from the ingot.[1] Uncontrolled abrasion in preparing test specimens from ordinary qualities of this steel is to be deprecated owing to the danger of partial exposure of the less pure interior layers which are more susceptible to corrosion. This material is obtainable in bright form free from scale and rust, so that only a simple degreasing should be necessary, or at the most a mild abrasive cleaning treatment, for which a light scrubbing with a slurry of fine natural pumice powder and water would be recommended. A test of this scrubbing treatment showed that it removed very little steel, at the most 0·01 mil thickness. Following the abrasive cleaning, the normal practice in the present work has been to swab the steel quickly with cotton wool and water, rinse with re-distilled acetone, suspend in warm, dry air for 1 hr, and cool in a desiccator.

Application of Protectives to be Tested.

Normally the protective was applied by dipping, then allowing the excess to drain off the specimen suspended upright in the air for 24 hr. Any drip was removed, and the weight of coating was obtained by increase in weight.

Hard or stiff coatings would be expected to remain at a known film weight during test. This may not hold in the case of oil films, owing to further drainage and evaporation which may occur during test, and hence caution is necessary in relating the protection obtained to the film weight that was applied in the first place. As an example the following results may be quoted :—

Oil	D.T.D.44B.	M.80.	M.220.
	(Film weight in mg/sq. in.)		
24 hr draining	1·3	2·7	4·2
4 weeks draining	0·2	0·9	1·4

all in room at the ordinary temperature.

Corrosion Tests.

1. *Outdoor Exposure.*

(a) *Test of Lanolin Coatings of Different Thicknesses on Steel.*

Method. Steel panels (4 × 2 in × 20 gauge) with solvent-deposited coatings applied by dipping in different lanolin solutions (Table I) were exposed outdoors, clamped in porcelain cleats at 10° to the horizontal, for a total of 4 to 5 months, and examined periodically on the top surface only. The exposure situation was an open one, approximately 2 miles W of

TABLE I.

Weight of Lanolin Films on Steel Panels.

Solution.		Weight of film (mg per sq. in.).		
		Dipped and drained at 0° C.	Dipped and drained at 23–24° C.	Dipped and drained at 40° C.
White spirit (B.S.S.245)	10%	0·2	0·5	0·7
	20%	0·9	1·3	1·5
	35%	3·9	3·1	3·3
	50%	—	6·8	5·9
Solvent naphtha (B.S.S.479A)	10%	0·3	0·6	0·8
	20%	2·1	1·5	1·9
	35%	8·4	3·6	4·3
	50%	—	9·0	7·6
Benzene (cryst.)	10%	1·1	1·6	2·1
	20%	3·5	3·6	4·0
	35%	16·2	8·6	7·9
	50%	—	15·8	15·9

The lanolin films applied at 0° C were uneven and channelled by condensed moisture.

Swansea, about ¼ mile from the coast of a sheltered bay, *i.e.*, a predominantly urban atmosphere; the weather conditions were mild and wet without marked fluctuations.

Results. Fig. 1 shows the life of the coatings plotted against the film weight. These results probably illustrate quite well the general trend of the effects of outdoor exposure on coatings of this type, bearing in mind that the actual values would be expected to vary with different atmospheres and weather conditions. The main effect is the thicker the coating the longer the life. The relation was substantially linear except for the thinnest films—those below 1·5 mg/sq.in, corresponding to about 0·1 mil thickness—where rusting commenced to occur disproportionately early. These thinner films would be rated as poorly protective under outdoor conditions. This is not to say that there is any actual change in the film at 0·1 mil thickness, but rather that the particular conditions of this outdoor test were too severe to reveal gradation between the thinner films. Differentiation between thin films can be shown under favourable weather conditions. Thus, in a further test on oil films (2 mg/sq.in) carried out subsequently at Woolwich, steel with a plain mineral oil rusted nearly all over in 24 hr (slight rainfall = 0·04 in) and developed in the same period only occasional spots of rust when the oil contained 13·5 per cent of oleic acid additive. This difference, however, entirely disappeared in a further 24 hr when there had been fairly heavy rainfall (0·5 in).

(b) *Other Coatings.*

Results of outdoor exposure at Woolwich (an industrial atmosphere) on coatings of different Service protectives are quoted in comparison with those of laboratory tests in Fig. 2. The thick-film protectives (50 mg/sq. in.

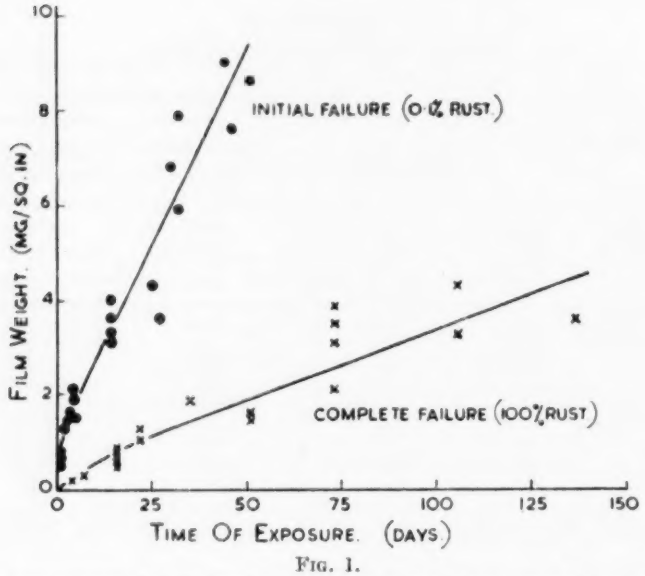


FIG. 1.

RUSTING OF LANOLIN-COATED STEEL IN OUTDOOR ATMOSPHERE. THE CURVES EMBRACE ALL SPECIMENS LISTED IN TABLE I, EXCEPT THAT THE INITIAL FAILURE CURVE DOES NOT INCLUDE SPECIMENS DIPPED AT 0° C, OWING TO IRRIGULAR COATING CAUSING EARLY FAILURE.

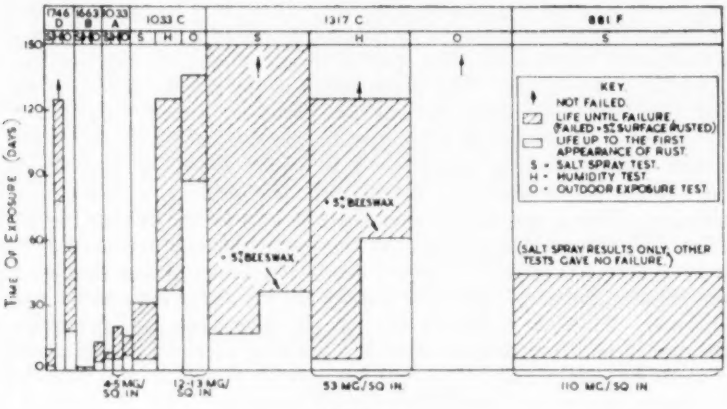
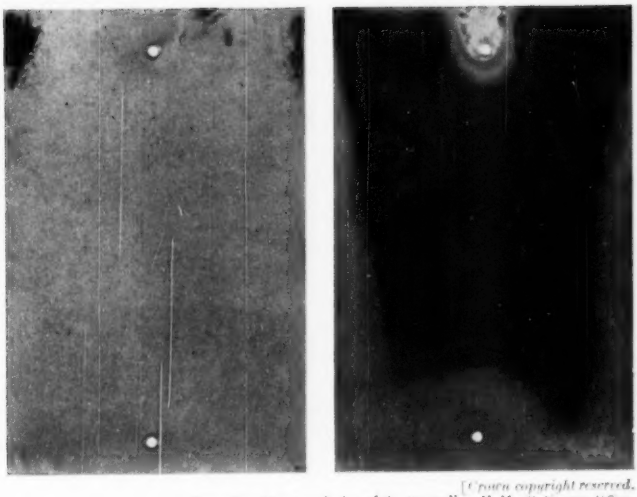


FIG. 2.

COMPARISON OF THREE METHODS OF TEST CONDUCTED ON SERVICE PROTECTIVES.

and upwards) gave excellent protection in the six months' exposure period used, as would be expected. Thinner-film materials varied considerably according to their nature, lanolin showing up relatively well.

An illustration of the good performance of lanolin as compared with oil



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A B

FIG. 3.

COMPARATIVE PERFORMANCE IN OUTDOOR EXPOSURE OF PHOSPHATED STEEL BASE TREATED WITH (A) LANOLIN, AND (B) MINERAL OIL.

The oiled specimen rusted considerably despite the fact that the weight of the oil (4·9 mg/sq. in.) was originally greater than the weight of the lanolin (1·1 mg/sq. in).

[*To face p.* 166.

was given by two specimens of phosphated steel treated with these protectives and exposed outdoors at 45° for twenty-eight days (Fig. 3). The poor protection by oil appeared to have been due largely to loss of oil film during the exposure, since estimation of the quantity remaining on the specimen after test gave the following results :—

Protective.	Before exposure.	Upper surface after exposure.	Lower surface after exposure.
	Film weight (mg/sq. in.) (average over surface).		
Lanolin . . .	1·1	0·5	1·1
Mineral oil . . .	4·9	0·5	1·3

Table II gives the results of hard-film protectives on steel and non-

TABLE II.

Protective Value of Hard-film Protectives on Various Metals.

Test conditions.	Metal surface.	Degree of protection.			
		D.T.D.663.	C.S.1033D.	C.S.1033 (Mod.[a]).	C.S.1033E.
Outdoor exposure 8 months (exposed surface = upper side of panel exposed at 45°)	Steel	Poor	Poor	Fair	Fair
	Brass	Fair	Good–very good	Good–very good	Good–very good
	Duralumin	Fair–good	Good	Good–very good	Good–very good
	Magnesium	Poor	Fair	Good	Good
Outdoor exposure 8 months (sheltered surface = under side of panel exposed at 45°)	Steel	Good	Fair	Fair–good	Fair–good
	Brass	Very good	Very good	Very good	Very good
	Duralumin	Very good	Very good	Very good	Very good
	Magnesium	Very good	Fair–good	Fair–good	Fair–good
A.R.E. salt spray 2 months	Steel	Poor–fair	Poor	Fair	Fair
	Brass	Fair–good	Good	Good	Fair–good
	Duralumin	Fair–good	Fair	Fair	Fair
	Magnesium	Poor–fair	Poor	Poor	Poor
Humid-condensation (100% R.H. at 40° C) 2 months	Steel	Fair–good	—	Good	Good
	Brass	Very good	—	Very good	Very good
	Duralumin	Very good	—	Very good	Very good
	Magnesium	Very good	—	Good	Good

Code : Very good = free from corrosion, no more than slight tarnishing of metal surface below the protective film.
Good = approx. 0·1% of surface corroded.
Fair = approx. 5% of surface corroded.
Poor = approx. 50% of surface corroded.

ferrous metals. A point of interest is the generally improved protection on the sheltered under-surface as compared with the top surface of the specimen freely exposed to rain and sun. This is especially the case with D.T.D. 663, and appeared to be related to deterioration by cracking on the top surface.

2. *Water-droplet Spray Test.*

This method, which employs water droplets applied to simulate the effect of condensation, was applied when a mild form of test was required, as with the thin oil film referred to below.

Method. The coated specimens are placed flat on a bench, and the approximately horizontal test-surface is covered with droplets of water applied from a spray (the same method is used as subsequently referred to in more detail under salt-spray test). The specimens are kept at ordinary room temperature protected from dust but not covered up, and the droplets are allowed to dry off spontaneously, requiring 1 to 2 hr. Spraying is repeated, with intervening drying off, until definite rusting occurs on one or more of the specimens being compared, the final assessment being made qualitatively according to the degree of rusting on the specimens. The method has also been used in a slightly modified form, in which the drying off is retarded by keeping the specimens in a loosely covered box, when spraying is only required once per day to renew the droplets.

Results of Tests on low-cold-test oil films. Plain mineral oils were poorly protective, as rust developed within a few hours. Oleic acid additions to the oil, up to the maximum content tested (13·5 per cent), markedly retarded rusting, and since the film thickness of oil was not increased by the additions, remaining at 1 to 2 mg/sq. in., the oleic acid had increased the protective value of the oil. Addition of triethanolamine with oleic acid (1·5 and 13·5 per cent respectively) made the film less water-repellent and the drops tended to spread and emulsify, but appeared to make no difference to the protective value in this test. Similarly, low-cold-test oil with the addition of 5 per cent of proprietory sodium petroleum sulphonate addition also tended to promote emulsification of droplets and the anti-rust value was about the same as that of the oil–oleic-acid mixture. Additions to low-cold-test oil of lanolin (0·5 per cent) and stearic acid (0·05 per cent) did not improve its protective value.

3. *Humidity–Condensation Test.*

Heavy condensation produced in humidity-cabinet tests employing highly supersaturated air may cause streaming and undesirable washing off. The production of a small, regulated degree of condensation from a warm, humid atmosphere is difficult to arrange, but the following method is in use for research purposes.

Method. The test specimens are preferably in the form of machined rods 2 × 1 in diameter, or blocks of similar size, as sufficient heat capacity is necessary; sheet material is generally unsuitable in this respect. The rods are supported in the air space of a glass desiccator vessel containing a little water at the bottom, and are arranged equidistant from each other at a distance of 1 to 2 in from the wall of the vessel. The vessel, closed except for a small breathing hole, is placed in a suitable water-jacketed oven, thermostatted at the desired temperature (100° F is normally used). Normally droplets of condensed moisture form on the surface of specimens which are situated nearest to the door of the oven by reason of slight loss of heat in this direction. The desiccator vessel is rotated through 45° at suitable intervals of time, usually one day, bringing all the specimens in turn through the condensation zone.

Results. The results of tests on various protectives are shown in Fig. 2 and Table II.

4. *A.R.E. Salt-spray Test.*

This method should be clearly distinguished from various salt-spray tests which are actually salt-fog tests, where salt water is sprayed into a vessel producing a fog in which the specimens are suspended. In view of difficulties in obtaining reproducible results without installation of elaborate equipment, as shown in recent American work,[2] salt-fog tests have not been proceeded with by the authors.

Method. The principle of the A.R.E. test is to cover the test-surface with droplets of salt water by a hand-operated spray. The specimens are then enclosed under a suitable cover to maintain a still, humid atmosphere to retard drying off. Re-spraying is done once per day to replenish droplets on the surface. The test may be conducted at room temperature (as is usual for ordinary purposes) or in a thermostat. The corrosiveness of the test may be checked by quantitative corrosion of bare steel control panels. Practical details of the method have been published in Section 4 of B.S. Specification 1391/47 [3] on the basis of investigations on permanent protective coatings.[4] In the present work the specimens were tested in the undamaged condition, *i.e.*, omitting the scratch and standard blow described in the B.S. specification.

Results.

(a) *Hard-film protectives.* See Table II.

(b) *Miscellaneous protectives.* Results in Fig. 2 showed that the salt-spray test was the most severe of the tests used. Out of the seven protectives tested, four with film weights in the thin to moderate range, viz., 1746D, 1663B, 1033A, 1033C, showed failure in each of the tests. Dividing the outdoor exposure life by the salt-spray life gives an indication of the "acceleration factor" of the salt-spray test. This works out on the average to a figure of 8·0 based on the life to first appearance of rust and a figure of 4·6 based on the life to 5 per cent of surface rusted, giving a mean figure of 6·0, with respect to outdoor exposure. One unexpectedly early failure was that of steel coated with lime-soap grease; this was due to rusting starting and spreading from thin areas in the rather uneven coating, particularly at edges.

(c) *Oil films.* The orders of merit of protective values obtained in two sets of tests of a number of oils on steel were as follows (they were based on the time to give 5 per cent of surface rusted) :—

Oil.	Order of merit. Salt-spray test.	Free exposure outdoors.
C.S.906 [a]	3	3
S.P.55 [b]	1	4
M.80 [c]	4	2
C.S.1663B [d]	2	1
M.80 [a] + Pet. sulphonate [e]	2	3½
S.P.55 [b]	1	3½
M.80 [c]	4	2
C.S.1663B [d]	3	1

(*a*) Triplicate specimens, (*b*) and (*d*) duplicate specimens, (*c*) single specimens. Initial film weights of (*a*), (*b*), and (*c*) ranged from 1·6 to 2·1 mg/sq. in., and (*d*) 2·4 to 4·0 mg/sq. in. (*e*) 5% of proprietary sodium petroleum sulphonate.

For description of oils see appendix.

(d) *Very thin mineral-oil films.* A batch of specimens was tested, having specially thin, solvent-deposited films of mineral oil M80 applied by dipping in dilute solutions of the oil in trichlorethylene. All developed rust in the first day's salt-spray test, the extent of rust being, however, rather less with the thickest of the films, but after 7 days little difference could be seen between the rusty condition of the specimens. At this stage, quantitative determination was carried out of the weight of steel corroded, and

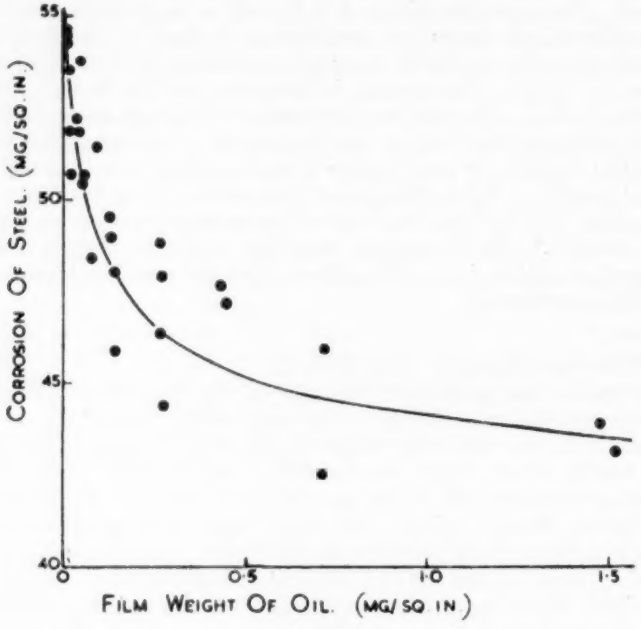

FIG. 4.

CORROSION IN SALT-SPRAY TEST (7 DAYS AT 25° C) OF STEEL WITH VERY THIN OIL FILMS.

confirmed that, in fact, the oil films had only reduced the corrosion slightly, by at most about 20 per cent. Nevertheless, it will be seen from the results plotted in Fig. 4, that the very thinnest oil layers had an appreciable effect, but this effect was not maintained proportionately as the layer thickened. It is pointed out that had the quantitative determination been done at an earlier stage, it is possible that the reduction in corrosion by the thinnest films would have been more pronounced.

DISCUSSION.

Correlation between the Tests.

Inspection of the various test results obtained indicates that the tests do not always agree in placing protectives in the same order of merit. Thus the orders of merit obtained from Fig. 2 based on the number of days for the first appearance of rust are as follows :—

Protective.	Order of merit.		
	Salt-spray test.	Humidity test.	Outdoor exposure test.
1746D	5	1	4
1663B	6	6	6
1033A	3½	4½	5
1033C	3½	3	3
1317C	2	4½	1½
1317C	1	2	1½

(A slightly different order of merit, not shown in these columns, is obtained when the basis is the life to failure by 5 per cent surface rusting.) The degree of concordance between these columns can be shown by Spearman's coefficient of rank correlation $\rho = 1 - \frac{6\Sigma d^2}{n^3 - n}$, where d = the numerical difference between the order of merit of the same material in two of the columns n = number in the series, in this case 6; if the concordance is perfect $\Sigma d^2 = 0$ and $\rho = 1$; if the discordance is perfect $\rho = -1$; in other cases ρ lies between these limits.

The values of Spearman's coefficient work out for the above figures as follows :—

Tests compared.	First rust.	5% rust.	Average.
Salt spray and outdoor exposure . .	0·89	1·00	0·95
Salt spray and humidity . . .	0·30	0·84	0·58
Humidity and outdoor exposure . .	0·47	0·84	0·66

Here the correlation between the salt-spray and outdoor-exposure tests is good, but that between the other tests is not so good.

Orders of merit can be derived from the short range of results on hard-film protectives in Table II, and it is found that, for the protectives on steel, the correlation between the free outdoor exposure, salt-spray, and humidity tests is almost perfect. This regularity is, however, not maintained with the protectives on non-ferrous metals. The results of sheltered outdoor exposure correlate poorly with the other tests, but it would be obviously unwise to draw any definite conclusion from such a limited number of results.

When it comes to oil protectives on steel, the order of merit of different oils in the salt-spray test does not correlate with that on free exposure outdoors, as shown by the results in Section 4 (*c*). This exception is, however, of little importance, as the " outdoor " order of merit is dependent to a large extent on the persistance of the oil film during test, and various oil films would be expected to differ in resistance to washing off by rain and to evaporation.

No values are yet available of inter-comparison between the water-droplet spray test and the humidity test.

Effect of Film Thickness.

The tests appear to confirm the expectation that, broadly, the protective value of a coating would increase with its thickness. The lanolin coatings exposed outdoors showed for the most part a linear increase of protection with thickness, but there is not enough information on coatings generally to make it clear how far linearity is typical. When we came to relatively thin films, the protection with lanolin exposed outdoors fell off rather

suddenly, but, as already pointed out, this may well have been due to poor discrimination afforded by the outdoor test, which is always liable to considerable fluctuations in intensity of the corroding conditions over short periods. By contrast, protection with thin oil films in salt spray did not fall off *pro rata* with decrease in film weight. Here, the test used supplies relatively constant conditions of corrosion enabling a more reliable comparison of films to be made.

Testing of Oil Films.

The considerable thinning of the oil film which can occur by a long period of drainage, causing reduced protection, merits attention. It may be questioned whether corrosion testing of oil films drained only for 24 hr, as is often done, has any practical use, since if the specimen were left for several months (*e.g.*, in storage) the film would have become thin and less protective. The answer would appear to be that a test on 24-hr-drained films would afford a side-by-side comparison of the protective value of different oils, especially if the films weights at that stage were closely similar. It would, however, be desirable to go further in testing, viz., to compare the oils also at the film thicknesses that they are likely to reach after prolonged drainage.

Conclusions.

The work, embracing tests largely of an exploratory nature, showed that in general each of the corrosion tests used has some value in comparing the protective value of the coatings.

Free exposure to the outdoor weather is a useful test on stiff coatings of reasonable thickness and long life, but is liable to be too variable and severe to be an appropriate test for oil type or other thin films. Nevertheless, in a favourable period, the protective life of lanoline coatings on steel was found to increase steadily with weight of coating, except for thin films of small protective value.

As is to be expected, the protective life is longer with coatings not directly exposed to sun and rain, but as shown in tests on a few Service protectives, the " protected exposure " life may be inconveniently long for the more durable types of coating.

Salt-spray testing conducted by the A.R.E. droplet-spray method, which was used in preference to the salt-fog method, gave promising correlation with free outdoor exposure on hard or stiff coatings on steel, and acted in a shorter time—approximately six times as quickly. It did not correlate well with outdoor exposure of oil films due, it is considered, to the oil films varying amongst themselves through extraneous factors such as washing off by rain and possibly evaporation in the outdoor test. Extremely thin films of oil exert a slight but definite protective action under salt spray, as determined by gravimetric corrosion test.

A humidity-cum-condensation test employing limited moisture condensation from a warm, saturated atmosphere appeared to be rather slow in action. The results did not show quite as good a correlation with outdoor exposure as the salt-spray test did. Little work has yet been done on the application of this method to testing oil films, but it may be of more value

for this purpose than humidity-cabinet tests employing strongly supersaturated air and heavy condensation which may cause washing off of the protective.

A water-droplet test has been used as a mild form of test, differentiating between thin films of oils. This method could be operated, if desired, at constant temperatures, ordinary or tropical, by the use of an air-thermostat.

Acknowledgment.

The authors wish to thank the Chief Scientist, Ministry of Supply, for permission to publish this work.

Appendix.

Description and Composition of Temporary Protectives Used.

Material.	Type of film.	Composition (by weight).
D.T.D.44B	Oil	Anti-freeze mineral oil of low viscosity
M.80, M.220	Oil	Plain mineral oils having Redwood No. 1 viscosities of 80 sec and 220 sec respectively at 140° F
C.S.906	Oil	Oil M.80, 85%; oleic acid, 13·5%; triethanolamine, 1·5%
C.S.1663B	Oil	Oil M.80, 85%; lanolin, 10%; kerosine, 5%
S.P.55	Oil	Mineral oil with anti-corrosive additive (proprietory)
C.S.1746D	Thin, soft film	Lanolin, 30–35%; coal-tar naphtha, 65–70%; green dye, 1·5%
C.S.881F	Thick, soft films	Lime-base grease
C.S.1317C	Thick, soft films	Mineral jelly
C.S.1033A	Thin, hard films	Rosin, 24%; lanolin, 15%; coal-tar naphtha, 58%; bitumen, 3%
C.S.1033C	Thin, hard films	Bitumen, oxidized No. 1, 19%; neutralized wool-grease, 13%; coal-tar naphtha, 24%; carbon tetrachloride, 44%
C.S.1033D	Thin, hard films	Bitumen, oxidized No. 1, 18%; neutralized wool-grease, 12%; coal-tar naphtha, 19%; trichlorethylene, 51%
C.S.1033E	Thin, hard films	Bitumen oxidized No. 1, 31%; dehydrated castor oil, 2%; zinc naphthenate, 2%; coal-tar naphtha, 17%; trichlorethylene, 48%
C.S.1033 (Mod.[4])	Thin, hard films	Bitumen oxidized No. 1, 29%, neutralized wool-grease, 4%; zinc naphthenate, 2%; coal-tar naphtha, 17%; trichlorethylene, 48%
D.T.D.663	Thin, hard films	Lanolin, 6 lb; resin, 4 lb; pool spirit, 8 pints; xylole, 2 pints; red dye, ¼ oz.

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Oilfield Exploration and Exploitation.

Geology.

1332. Tectonic framework of southeastern United States. P. B. King. *Bull. Amer. Ass. Petrol. Geol.*, 1950, **34**, 635–71.—This paper was originally presented at the Symposium on Mineral Resources of Southeastern States at the University of Tennessee. The author reviews the tectonics of the Paleozoic mountain system of the southeastern states of the U.S.A. This system is represented conspicuously by the structures of the Appalachian Highlands, but other structures occur in the Ouachita Mountains and other ranges west of the Mississippi Embayment.

The Appalachian Highlands are classified into five main groups, and the Appalachian system of the southeastern states is assumed to have been deformed mostly towards the end of Paleozoic time. However, there is evidence also of earlier movements, beginning with the Middle Ordovician.

The author suggests that the Ouachita system is a westward extension of an interior belt of the Appalachian system which has been thrust northwards to a moderate extent over the western extension of the belt of the Valley and Ridge Province.

The paper is illustrated by numerous tectonic maps and cross-sections. E. N. T.

1333. Field name, company, location, and initial production of discovery wells. Anon. *Oil Gas J.*, 26.1.50, **48** (38), 256.—The 1949 U.S. discovery wells are listed, grouped according to districts, with the name, month of discovery, company, location, producing sand, total depth, and producing interval, initial production, and oil gravity.

G. D. H.

1334. Discoveries, new pays in 1949—their size and location. Anon. *Oil Gas J.*, 26.1.50, **48** (38), 305.—The 1949 U.S. discoveries are grouped by districts with the following data: field, county, producing formation, proven acreage, formation thickness, and estimated reserves. G. D. H.

1335. Proven reserves of both gas and liquid show good gain. C. J. Deegan. *Oil Gas J.*, 26.1.50, **48** (38), 190.—At the end of 1949 the U.S. reserves of crude oil, condensate and other natural-gas liquids were estimated at 28,586,000,000 brl. This was 1,261,000,000 brl more than at the beginning of the year. The dry gas reserves were 178,136,000,000,000 cu. ft. at the end of 1949, an increase of 2,949,000,000,000 cu. ft. during the year.

Tables give by states the U.S. reserves at the beginning of 1949 and 1950, with the 1949 production, the reserves added by 1949 discoveries, and by extensions and revisions in 1949. The ratio of reserves to production is given for the beginning of 1948, 1949, and 1950; the overall ratios for the U.S.A. are, respectively, 12·5, 12·1, and 13·8. G. D. H.

1336. Exploration drilling reaches new all-time high records. P. De Armond. *Oil Gas J.*, 26.1.50, **48** (38), 180.—7294 wildcats were completed in the U.S.A. in 1949, the aggregate footage being 29,283,000 ft. 17·6% of the wells found oil or gas. This success ratio was lower than in 1948. Texas had 2791 wildcats, of which 15·8% had found oil and 4·0% found gas.

Tables summarize the U.S. exploration results by states, and compare the 1948 and 1949 wildcat footages. G. D. H.

1337. 3·7 percent increase made in exploratory drilling. C. W. Smith. *World Oil*, 15.2.50, **130** (3), 57.—7464 exploratory wells were drilled in the U.S. in 1949, compared with 7197 in 1948. 20·4% of these were producers, compared with 19·7% in 1948. 675 wells found new fields, and 284 found new pays. There were 150 natural-gas discoveries, of which 122 were new fields, and twenty-eight new pays in existing fields.

Two tables give the results of 1949 exploratory drilling in the U.S., by states and comparisons with earlier years. C. A. F.

1338. Wildcatting success gains percentagewise in 1949. Anon. *World Oil*, 15.2.50, **130** (3), 60.—6680 strict wildcats were completed in the U.S. in 1949, compared with 6182 in 1948. 13% found production. Texas was the most active wildcatting area, with 2841 tests.

A table shows the ratio of U.S. wildcatting to all drilling, and the proportion of wildcats discovering new fields, by districts, 1937–49. C. A. F.

1339. Second gas field in Arkansas. Anon. *Petrol. Engr.*, Nov. 1949, **21** (12), B–86.—1 Ralph S. Barton, in Franklin County, had an initial production of 7 M.c.f. gas from the Hale sand from 4870 to 4930 ft.

1 Mrs Ethel Hicks, in Crawford County, flowed 2 M.c.f. gas from 1842 to 1847 ft. C. A. F.

1340. Arkansas exploration due to continue rapid pace. Anon. *World Oil*, 15.2.50, **130** (3), 66.—Four oil and two gas fields were discovered in Arkansas during 1949. The oil discoveries opened the Pine Tree and Spotville fields in Columbia, Curry field in Ouachita, and the Loutre field in Union. The Smackover, at approx 8000 ft, is believed to be the most extensive pay. The gas discoveries opened the Cecil field in Franklin County, and the Rudy field in Crawford County. The Cecil discovery had a potential of 7 M.c.f. gas/day. C. A. F.

1341. Californian's take cautious view of prospects for 1950. Anon. *World Oil*, 15.2.50, **130** (3), 70.—Development of heavy-oil fields is being curtailed. Future exploration will be concentrated on developing light-oil areas, such as the Cuyama Valley. Deep tests will be drilled in the Newhall–Castaic area, and there may be wildcatting in the Santa Cruz area. Major 1949 discovery was the South Cuyama field, where forty-five wells had been completed by the end of the year. Estimated reserves

are 125–150 million brl. The Placerita Canyon field, discovered in March, reached peak production in September of 34,500 b.d. Intensive close drilling caused production to drop to 25,000 b.d. at the end of January. Generally, 1949 discoveries in the state were small, and the overall reserve declined. C. A. F.

1342. Geology of the Placerite oil field, Los Angeles County, California. G. B. Oakeshott. *Calif. J. Mines & Geol.*, **46** (1), 43.—The Placerita field is approx 2 miles east of Newhall in western Los Angeles County. The discovery well was completed in April 1948, and to June 1949, sixty-eight wells had been drilled. Production per well varies from a few brl to over 100 b.d. of 11–16° oil from 600 to 1600 ft. In Jan. 1949, Juanita 1, 1 mile north of the discovery, developed a northern extension of the field, where wells now average 550 b.d. of 22° oil from 1300 to 2100 ft.

The geology of the area consists essentially of Tertiary beds dipping northwestwards off the basement, exposed in the western San Gabriel Mts. Miocene and Lower Pliocene outcrop. Local structure is dominated by the San Gabriel fault, which trends northwest, and there are a number of asymmetrical anticlines and synclines subparallel to it. Faulting and folding began during the Upper Miocene and continued to Recent.

Wells are distributed in two groups; one along or near the main northeast trending axis of the Placerita anticline, where there is pump production from approx 200 ft of sands of the Upper Pliocene Pico; the other to the north of the axis, where production is also from the Upper Pliocene and some of the wells are flowing.

Structural features causing the accumulation are the westward-plunging Placerita nose and the San Gabriel fault and associated folds. Updip lensing and minor unconformities assisted in trap formation. Source rocks may be nearby Eocene, Miocene, and Pliocene organic shales.

The successful development of this field indicates that favourable structures involving marine Tertiary dipping off the basement in southern California are worth exploration. C. A. F.

1343. Deepest producing well. Anon. *Petrol. Engr.*, Nov. 1949, **21** (12), B-86.—Mushrush 5, in Wasco field, California, was completed for production in Eocene sand at 15,250–15,530 ft, where hole temperatures up to 325° F were recorded. C. A. F.

1344. Colorado activity expected to experience new decline. Anon. *World Oil*, 15.2.50, **130** (3), 70.—Drilling activity in Colorado during 1950 is expected to decline, as a result of unsuccessful wildcatting in 1949.

The Borie discovery indicated good Muddy Sand possibilities in northeast Colorado, but subsequent tests were unsuccessful. A well drilled at Oak Creek in Routt County was completed for 300 b.d. pumping production, but is now shut in. A gas well at Asbury Creek, in Mesa County, produced 2 M.c.f. gas/day from the Dakota. C. A. F.

1345. Illinois exploratory drilling may exceed activity of 1949. Anon. *World Oil*, 15.2.50, **130** (3), 68.—Chief developments in 1949 were discoveries in Wayne, Marion, and Fayette counties. In Wayne, Richardson 1 opened the South Zenith pool, with an initial production of 675 b.d. from McClosky Lime at approx 3000 ft. In Marion, Franke-Mayerl opened the Raccoon Lake field with 215 b.d. from the Rosiclare and McClosky. In Fayette, Grames 1 found the first of three extensions to the London pool. C. A. F.

1346. Exploration in Indiana due to keep pace with old year's. Anon. *World Oil*, 15.2.50, **130** (3), 68.—Outstanding 1949 discoveries were the Marts pool in Sullivan County and the Blackhawk pool in Vigo County.

The Marts discovery, Bollinger 1, produced initially only 50 b.d. from the Devonian, but later wells were more productive.

The Hunkwork well, which discovered Black Hawk, initially produced 100 b.d. from Devonian at 1845 to 1875 ft. C. A. F.

1347. Opens gas pool in Indiana. Anon. *Petrol. Engr.*, Feb. 1950, **22** (2), B-74.—A well drilled in Davies County blew gas from the Salem Lime from 1120 ft. A

second well, 50 ft away, was completed for a flow of 225–230 b.d. of 40° oil from the Fredonian from a total depth of 744 ft. C. A. F.

1348. Hugoton field may repeat as brightest spot in Kansas. Anon. *World Oil*, 15.2.50, **130** (3), 68.—During 1949, 260 trillion cu. ft. were sold from the Hugoton field, 21% more than in 1948. 1949 discoveries in the state include: the Davis Ranch field in Wabaunsee County, which at the end of the year had nine wells with a max potential of 3000 b.d/well, and the Huffstutter pool, which produces from the Lansing–Kansas City Lime. C. A. F.

1349. Cities service finishes 3000 barrel producer. Anon. *Petrol. Engr.*, Nov. 1949, **21** (12), B-85.—Saindon 4, in Rooks County, Kansas, was completed for 3000 b.d. from the Arbuckle at 3559 ft.

Rhiness 1, in Seward County, Kansas, was completed for an open flow of 18,600,000 cu. ft. gas/day. C. A. F.

1350. Kentucky expects good year as fuel demand sharpens. Anon. *World Oil*, 15.2.50, **130** (3), 70.—One of the most important 1949 discoveries was the East Caney-Mound field. The discovery, Walker 1, in Union County, had an initial production of 370 b.d. from the McClosky Lime from 2510 to 2520 ft. C. A. F.

1351. Phillips completes gas well. Anon. *Petrol. Engr*, Nov. 1949, **21** (12), B-85.—1 Samantha, in De Soto Parish, Louisiana, was completed for an open flow of 44 M.c.f. gas/day from the Pettit Lime. C. A. F.

1352. Extension of Smackover is major North Louisiana goal. Anon. *World Oil*, 15.2.50, **130** (3), 66.—S. W. Owens 2, in Claiborne Parish, completed in 1949, extended the Smackover pay in the East Haynesville field 2¾ miles northeastwards. Further development of Smackover production is expected during 1950. During 1949, two fields were discovered in the Shreveport area, and two Wilcox fields in Concordia Parish near the Mississippi border. C. A. F.

1353. South Louisiana tidelands to get major development. Anon. *World Oil*, 15.2.50, **130** (3), 66.—There were fifteen discoveries, including new pay sands, in the Gulf during 1949. Deepest was in the Weeks Island field, Iberia Parish, where pay was discovered at 14,015–14,025 ft. Chief development was in the Bay Marchand area off the coast of Lafourche Parish, where the discovery well found four pays between 2873 and 5092 ft. C. A. F.

1354. Michigan exploratory work to maintain same rate. Anon. *World Oil*, 15.2.50, **130** (3), 70.—A number of small fields were discovered in 1949, most of which were near older fields. There were new developments in the 5000-ft Richfield horizon in Gladwin, Bay, and Ogemaw Counties. Eight wells, whose potential varied from 100 to 1500 b.d., were drilled in the South Adams field. C. A. F.

1355. Year-end spurt in activity maintained in Mississippi. Anon. *World Oil*, 15.2.50, **130** (3), 66.—Smith 1, near Laurel in Jones County, had an initial potential of 2,320,000 cu. ft. gas and approx 11 b.d. of condensate from the Eutaw at 5505–5540 ft.

Zeigler 1, in Lincoln County, flowed 375 b.d. on test.

Bass Unit 1, in the Bude field of Franklin County, flowed 604 b.d. of 43·8° oil. C. A. F.

1356. Mississippi gets Travis Peak oil. C. J. Deegan, *Oil Gas J.*, 16.2.50, **48** (41), 149.—1 Wilson, ½ mile north of the shallow production limits at Pickens, has flowed 200 b.d. of 42° oil from the top of the Travis Peak (Hosston) at 7730–7732 ft. The well found the following: Wilcox (1291 ft), Midway (3134 ft), Selma (3950 ft), Eutaw (4806 ft), Tuscaloosa (5583 ft), Glen Rose (6254 ft), Hosston (7765 ft), Cotton Valley (9350 ft), Smackover (11,210 ft), and salt (12,219 ft). Side-wall cores gave favourable shows at 7510–7546 ft, 7640–7690 ft, 7730–7766 ft, 7818–7827 ft, and 7865–7880 ft. Hosston permeabilities ranged up to 686 mD, and porosities 12·2–22·4%. The accumu-

lation is assumed due to the main faults on the north side of the Pickens field. The nearest production of similar age is some 100 miles distant. G. D. H.

1357. Widespread exploration due to take place in Montana. Anon. *World Oil*, 15.2.50, **130** (3), 72.—Small but important discoveries were made in 1949, chiefly in the Clark Fork area of Carbon County. A Dakota sand discovery well produced 2,244,000 cu. ft. gas and 31 b.d. of 57·7° distillate. C. A. F.

1358. Increased drilling likely for Western Nebraska. Anon. *World Oil*, 15.2.50, **130** (3), 72.—A well completed in 1949 at Gurley in Cheyenne County, pumped 225 b.d. of 35° oil from the First Dakota. This was the first commercial oil discovery in Western Nebraska. Gas has since been found in the Huntsman area, near Gurley, where a well flowed 12½ M.c.f. gas/day from the Third Dakota. C. A. F.

1359. New Mexico deep discoveries assure heavy development. Anon. *World Oil*, 15.2.50, **130** (3), 63.—Deep drilling in Lea County in 1949 opened up new areas for development. Elsewhere in the state drilling was uneventful.

Seven of the new fields produce from below 9400 ft. In the Bagley area, flush production was proved from the Siluro–Devonian at 10,965 ft, and sweet crude production from the Pennsylvanian at 9000 ft.

Other discoveries include Devonian oil at 10,100 ft in the High-tower area and at 12,600 ft in the Knowles field, and Pennsylvanian oil from 9600 ft in the Bough field. C. A. F.

1360. Gas well discovered in San Juan basin. Anon. *Petrol. Engr*, Feb. 1950, **22** (2), B-78.—A well drilled approx 10 miles east of Blanco (New Mexico) produced 1,400,000 cu. ft. gas/day from the Mesa Verde, topped at ± 4400 ft. C. A. F.

1361. Decline in Ohio exploratory drilling is probable for 1950. Anon. *World Oil*, 15.2.50, **130** (3), 70.—Large unexplored areas in Ohio are probably gas bearing, but prices do not at present favour their development. A wildcat in Erie County found a little oil in the Trenton, and a small pool was discovered in Vinton County. A gas pool discovered in Lorain County will be developed in 1950. C. A. F.

1362. Oklahoma operators expect year of heavy development. Anon. *World Oil*, 15.2.50, **130** (3), 68.—1949 development centred in the Golden Trend area, in southern Oklahoma, and in the new Elk City pool in the west. Average depth of wells is 5000 ft. In Okfuskee County and south Tulsa County, extensions to old areas were found. A 14,000 ft test in Ellis County is planned. C. A. F.

1363. Flows 1167 barrels in 24 hr. Anon. *Petrol. Engr*, Nov. 1949, **21** (12), B-86.—1 Oklahoma State "A," in Beckham County, Oklahoma, was completed for 1167 b.d. of 46° oil from a total depth of 10,044 ft. G.O.R. was 1468 : 1. C. A. F.

1364. Wilcox well flows 1200 barrels a day. Anon. *Petrol. Engr*, Jan. 1950, **22** (1), B-70.—Walker 2, in Beckham County, Oklahoma, had an initial production of 1200 b.d. of 43° oil and 2 M.c.f. gas/day. C. A. F.

1365. Mechanics of Appalachian folding as illustrated by Sequatchie anticline, Tennessee, and Alabama. J. Rodgers. *Bull. Amer. Ass. Petrol Geol.*, 1950, **34**, 672–81.—In recent times two different views on the mechanics of the folding in the Appalachian Valley and Ridge Province have grown up. The first theory believes that the folds in the Paleozoic sediments are reflections of adjustments in the underlying basement. The other theory believes that the folds are quite independent of the basement. This paper attempts to analyse one of the more prominent Appalachian folds.

The Sequatchie anticline of Tennessee and Alabama has been used as evidence in support of both the above schools of thought. The theory of the second school requires transverse faults at each end of the fold.

The author points out that these folds are present, but that their significance has

generally been overlooked. Further application of the theory to this anticline may suggest the presence of two windows, comparable with the oil-bearing windows of Lee County, Virginia. E. N. T.

1366. Arick field. G. F. Shepherd. *Petrol. Engr*, Nov. 1949, **21** (12), B-11.—The Arick field, in Hale and Floyd counties, Texas, is on the Matador arch, which separates the Permian and Palo Duro basins. The structure was located by torsion-balance, gravity, and reflection work, and was confirmed by the discovery well, 1 Byrd, in 1941. The high is a prominent east–west ridge with a gently dipping north flank, and steep south and west flanks. Production is from porous zones in the Pennsylvanian and Wolfcamp limestones.

The structure of the field is described in detail, and four structural maps are included. C. A. F.

1367. Woodlawn field adds well. Anon. *Petrol. Engr*, Feb. 1950, **22** (2), B-72.—1 Texie Davis, in Harrison County, Texas, was rated for 58,500,000 cu. ft. gas/day from the Pettit from 6404 to 6580 ft. C. A. F.

1368. Texas Panhandle test gets oil in Penna. C. J. Deegan. *Oil Gas J.*, 2.2.50, **48** (39), 97.—North of the Amarillo mountains in Sherman County 1 Willclo has pumped 225 b.d. of 40° oil from perforations opposite the Pennsylvanian at 5844–5880 ft. The well is 2 miles north of 1 Kathryn, which found gas in the Pennsylvanian.

Both wells had gas in the Permian pay of the Hugoton field. The Lips pool to the southeast in Roberts County was opened by a well which had gas in the Pennsylvanian, and oil in the Mississippian. A mile to the north a Pennsylvanian gas-distillate producer was opened.

A small uplift appears to lie north of the Amarillo mountain uplift. Little granite wash has been found on it, and the section thins over it. G. D. H.

1369. Texas Panhandle advances deep production campaign. Anon. *World Oil*, 15.2.50, **130** (3), 63.—In the Anadarko basin, deep-flowing production has been found from the Mississippian at 8900 ft, and high-pressure gas from the Pennsylvanian. A well drilled to the Mississippian on Lips Prospect, Roberts County, found 35° oil, set.,pt. 82° F. M. J. Boney-Katheryn 1–A, in Sherman County, flowed 19,350,000 cu. ft. sweet gas/day from the Pennsylvanian from 5312 to 5425 ft. Williams–Willclo I, also in Sherman County, is being completed as a 39° oil pumper from 5844 to 5880 ft. C. A. F.

1370. Heavy drilling expected on flanks of Texas coast domes. Anon. *World Oil*, 15.2.50, **130** (3), 64.—A number of oil and gas reserves were discovered in the Texas Gulf Coast area during 1949, as a result of flank drilling of established salt domes. Twenty-five gas pools were found. Discoveries were concentrated along the Wilcox trend. C. A. F.

1371. McClanahan drills well in Guadaloupe County. Anon. *Petrol. Engr*, Jan. 1950, **22** (1), B-70.—F. D. Glass 1, in Guadaloupe County, Texas, had an indicated flow of more than 1000 b.d. from 2414 ft. Pay is believed to be Austin chalk. C. A. F.

1372. Sunray gets new well. Anon. *Petrol. Engr*, Jan. 1950, **22** (1), B-72.—"B" 8, in the J. P. Smith, block 1, in Scurry County, Texas, flowed on test 1024 b.d. from a total depth of 6893 ft. Pay is reef limestone. C. A. F.

1373. Scurry County's new reef fields. D. H. Stormont. *Oil Gas J.*, 2.2.50, **48** (39), 46.—Oil production has been fairly well established along a Canyon reef mass for a length of over 20 miles and a width of up to 6 miles. Assuming that 50,000 acres will produce, from an average pay thickness of 200 ft, with about 50% saturation and a recovery of 200 brl/acre-ft, the reserves may be 1,000,000,000 brl. North Snyder has leases with 80% saturation of a 600-ft section, and recoveries by pressure depletion are expected to exceed 225 brl/acre-ft. Production is 6700–7000 ft deep. The best

porosity is in wells high on the reef. 325 producers have been drilled. The reef ranges from vuggy to tight, and average porosities of 16% have been measured in some cases. In one well a section of 250 ft had an average permeability of 17 mD. Limited work indicates 25% of interstitial water. The crude is undersaturated and has 800 cu. ft. of gas/brl. At North Snyder the saturation pressure is 1725 p.s.i.g., but at Diamond M the figure was 1946 p.s.i.g. The latter had 1052 cu. ft. of gas dissolved per barrel of oil, and the oil shrank to 0·622.

The reef is believed to be surrounded by shale except for resting on relatively thin Strawn. Reef production has been found 8 miles northeast of North Snyder and 4½ miles west of Sharon Ridge. G. D. H.

1374. Diamond M field extended. Anon. *Petrol. Engr*, Feb. 1950, **22** (2), B-72.—1 Dee Myers, in Scurry County, Texas, was completed for 1080 b.d. from perforations from 6820 to 6840 ft and open hole from 6848 to 6851 ft. The well is approx 1 mile north of the Diamond M field. C. A. F.

1375. North, west, central Texas areas to be highly active. Anon. *World Oil*, 15.2.50, **130** (3), 63.—Most of the discoveries in north-central and west-central Texas in 1949 were deep Pennsylvanian and Mississippian zones. Important developments were the discovery of the Pardue multi-pay area in north-eastern Fisher County and the extension of the Roundtop multi-pay field. Both produce from reef structures. C. A. F.

1376. Major development unlikely in new East Texas area. Anon. *World Oil*, 15.2.50, **130** (3), 64.—The majority of the 1949 discoveries in E. Texas yielded low-gravity oil, following recent trends. Development of heavy-oil producing areas is restricted.

Relaxation of well-spacing restrictions at the East Texas fields permitted the drilling of new wells to the Woodbine pay.

In Wood County, production from the sub-Clarksville sand was found in five areas. Structures are narrow and faulted. The Woodbine is locally productive.

Flowing high-gravity oil from the Upper Rodessa and gas condensate from the Lower Rodessa were found in deep wells in Anderson and Smith Counties. Condensate was also found in Freestone County. C. A. F.

1377. B–A opens North Texas pool. Anon. *Petrol. Engr*, Jan. 1950, **22** (1), B-74.—A well in northwestern Young County, North Texas, was completed to flow a calc potential of 1444 b.d. of 40·7° oil from Mississippi lime from 4085 to 4911 ft. C. A. F.

1378. Deep production replacing shallow pay in North Texas. Anon. *World Oil*, 15.2.50, **130** (3), 63.—Most of the 1949 discoveries in N. Texas were deep Pennsylvanian, Mississippian, and Ellenburger zones, which are steadily replacing the shallow fields as the district's main source of future oil production. C. A. F.

1379. South Texas gas discoveries to be developed this year. Anon. *World Oil*, 15.2.50, **130** (3), 64.—Most of the gas strikes in S. Texas during 1949 were from 4000 to 8000 ft, but locally there were shallow finds, as in the Staples area of Caldwell County at 670 ft. Oil was found at 980 ft near Lund, Travis County. The deepest gas well was in San Patricio County, and was completed at 9984 ft.

Nine pools and seven gas reserves were opened in Duval County, where drilling is comparatively shallow. Gas condensate was found in Goliad County from the Yegua and Wilcox. Six oil pays discovered in the La Copita field, Starr County, range from 4844 to 6834 ft.

A well in the La Sal Vieja area, Willacy County, flowed oil from 8329 to 8344 ft. C. A. F.

1380. Impact of West Texas find to linger throughout 1950. Anon. *World Oil*, 15.2.50, **130** (3), 62.—As a result of 1949 discoveries, further exploration in Scurry and adjacent counties is expected to reveal more important Pennsylvanian reef fields along a north–south trend on the east side of the Permian basin.

Linking of proved areas and new step-out wells confirmed 45,000–50,000 acres of

Pennsylvanian production in Scurry County during 1949. Pay thickness and potential varies considerably. The North Snyder sector has the greatest reef development above oil–water level. 300–500 ft of unbroken pay is common. Other Scurry County developments in 1949 include the three widely separated Ellenburger pools, Mississippian pumping production, and Strawn production on the east side of the North Snyder area and on the south-east side of the Kelly field.

Major discoveries in the Central Platform and the Midland Basin during 1949 were the Pegasus and Flanagan multi-pay fields.

It is planned to drill over 100 wells on the south and southwest flanks of the Goldsmith field, where a 3-mile southward extension of the Clearfork " 5600 " pay has been proved. C. A. F.

1381. North and Midland basin gets pre-Permian oil. C. J. Deegan. *Oil Gas J.*, 26.1.50, **48** (38), 375.—Nearly 100 miles north of the nearest basin pre-Permian production at Pegasus 1 Nystel has flowed 35·5° oil at 48 brl/hr from perforations at 11,475–11,542 ft, after acidization. The G.O.R. was 23 in a later test. This well is 14 miles southeast of Brownfield, and 4 miles east of Adair, where the Permian produces. Possible production was indicated in the Pennsylvanian above the Fusselman in a test of 9350–9375 ft. The seismic picture does not indicate a large field, but the find is expected to encourage pre-Permian prospecting in a number of counties between Pegasus and the discovery which may be called the Corrigan field. G. D. H.

1382. Discoveries in Uintah County stimulate interest in Utah. Anon. *World Oil*, 15.2.50, **130** (3), 70.—A well drilled in the basal Wasatch at Roosevelt, which produced 600 b.d., renewed interest in the Salt basin area. C. A. F.

1383. Washington State test has good show. C. J. Deegan. *Oil Gas J.*, 19.1.50, **48** (37), 99.—3 State, north of Olympia in Thurston County, Washington, has given gas and a spray of 42° oil from perforations at 3670–4400 ft and 4663–4478 ft. The zone, which is of Middle Miocene or Oligocene age, is dominantly shale with strings of silty sand. The well is 9344 ft deep, and swabbed water and a little gas from below 7159 ft.

1 State, 50 ft north of 3 State, was abandoned in 1948. To the north 1 Bannse was abandoned at 4330 ft. In Kitsap County 1 Hoffert is below 4000 ft. In Grays Harbour County 1 Weyerhauser reported a good gas show in drilling to 6608 ft, while 2 State was taken only to 3775 ft. North of these two tests 1 Milwaukee Land Co. reached 5600 ft in Jefferson County, and 1 Rayonier 2350 ft in Clallam County. G. D. H.

1384. Pore-space reduction in sandstones. Jane M. Taylor. *Bull. Amer. Ass. Petrol. Geol.*, 1950, **34**, 701–16.—Results are presented of a study of pore-space reduction in sandstones in two deep wells in Wyoming.

Thin sections of five sands were studied, and tentative criteria are presented whereby three types of pore-space reduction can be recognized in thin sections.

Sand-grain contacts as they appear in the plane of a random thin section are classified, and a number of interesting features are noted.

To date, no depth relationship can be established, but it is thought that this type of study, if expanded, may furnish a method of forecasting sand porosity at depth. E. N. T.

1385. Wyoming exploratory work due to maintain brisk pace. Anon. *World Oil*, 15.2.50, **130** (3), 72.—A wildcat at Pacific Creek, Sublette County, was abandoned at 20,521 ft after a number of tests. The Frontier was topped at 19,720 ft, but the Dakota was not reached.

1949 discoveries include oil in the Muddy Sand near Glenrock, Sundance production at Lightning Creek, and Lakota and Shannon pay in the Sussex area of Johnson County.

Wells are to be drilled in the Riverton field of Fremont County, where a deep test flowed 485 b.d. of 48·2° oil from the Tensleep. C. A. F.

1386. Recent Canadian oil developments. J. D. Gustafson. *Petrol. Tech.*, Dec. 1949, **1** (12), 8–15.—The west Canadian basin covers about 800,000 sq. miles, and in the Rockies up to 50,000 ft of sediments may have been deposited, and even in the eastern foothills the sediments may be 18,000–20,000 ft thick. Palæozoic beds outcrop on both sides of the basin. The sediments thicken from east to west, and in the east the dips are a few ft/mile. Surface glacial deposits are extensive. Up to the beginning of October 1949 only eighteen wells had reached the Pre-Cambrian. Through most of Alberta Middle Devonian rests on Cambrian. Permian is absent everywhere, and Lower Cretaceous rests on progressively older beds eastwards. Upper Devonian pools occur at Leduc–Woodbend, Redwater, Golden Spike, and Stettler. At Leduc the D-1 zone underlies Lower Cretaceous and is largely dolomite or dolomitic limestone with a little chert and anhydrite. It is 220–460 ft thick. Below anhydrite and mottled silts and clayey rock is the 145–165-ft thick D-2 zone. This is dolomite. A green shale zone separates the D-2 and D-3 zones. The top of the D-3 is detrital with a bioherm below. This reef is 700 ft thick. The D-3 closure is depositional; the arching above is believed to be compactional. The D-2 may be a local shoal reef.

Current light-oil crude demand in Alberta is about 60,000 b.d. The present efficient potential may be over 120,000 b.d. A pipeline from Edmonton to Regina and Lake Superior is expected to be completed early in 1951.

Devonian pools are 1800 (Norman Wells) to 6700 ft deep (Normandville). Cretaceous pools are less than 2000 ft deep in Western Saskatchewan, while the Madison is at 12,000 ft deep in the foothills. Lost circulation is troublesome in the Devonian, leading at times to blow-outs. Diamond coring in the bioherms has given over 95% recoveries. Footage per bit has risen from 225 to 450 ft. In the D-2 zones open-hole completions are made; perforated liners are usually set in the D-3 zone at Leduc, but not at Redwater, where there is no gas cap. All the large Devonian pools have flowing wells initially. So far emulsion treatment has not proved difficult. Paraffin is deposited in the tubing and flow lines, especially at Redwater.

The D-2 zone at Leduc has only small and local gas caps, and no extensive water body; the D-3 zone has a large gas cap and a thick water zone. The D-3 zone at Redwater has no gas cap, but a thick water zone. The D-2 zone has an average effective porosity of about 10% and a permeability of about 25 mD. The D-3 reef averages 13% porosity and 300 mD permeability at Leduc; at Redwater the corresponding figures are 10% and 800 mD.

A number of tables, maps, and sections are included. G. D. H.

1387. Reefs can do peculiar things. C. J. Deegan. *Oil Gas J.*, 9.2.50, **48** (40), 115.—The Golden Spike, Alberta, discovery was rated at 10,000 b.d. from a 550-ft pay section. It is less than 5 miles from Woodbend, but the pay is several hundred feet below the Woodbend water level. No. 2 Golden Spike and No. 3 Golden Spike, respectively about 3 miles northeast and 3½ miles northwest of the discovery were dry. No. 4, about 1 mile northeast of No. 1, was a good well. No. 5, ½ mile west of No. 4, found the D-2 zone productive. The others produced from the D-3 zone.

G. D. H.

1388. Gas well discovered in British Columbia. Anon. *Petrol. Engr*, Jan. 1950, **22** (1), B-77.—A well approx 20 miles south-east of Fort St John, in the Peace River area, on test flowed 416,000 cu. ft. gas/day from a Triassic sand from 4835 to 4849 ft.

A second gas pay was found below 4900 ft. C. A. F.

1389. Mexico success. Anon. *Oil Gas J.*, 19.1.50, **48** (37), 39.—1 Tortuguero in southern Veracruz has found two oil sands between 5904 and 6298 ft in the Lower Miocene and possibly Upper Oligocene. Brief tests have indicated flows of 100–150 brl/hr. The well is directionally drilled to a point 2000–3000 ft offshore.

A wildcat at Xicalango in the state of Campeche is reported to have had a strong gas show at less than 4000 ft. G. D. H.

1390. South America's oil resources and oil policies. J. E. Rassmuss. *World Petrol.*, Jan. 1950, **21** (1), 38.—In 1948 South America and Trinidad produced 554,635,000 brl of oil, or 16·3% of the world output, all but 65,000,000 brl coming from Vene-

zuela. South America is credited with 9,700,000,000 brl of reserves, 8,800,000,000 brl being in Venezuela.

In Brazil crystalline rocks outcrop over 75·3% (nearly 5,000,000 sq. km.) of the surface; only 5·7% of the area seems to have major oil possibilities. Production at Reconcavi is from faulted anticlines in a Cretaceous graben. Reserves are placed at 17,800,000 brl, and there are eighty producing wells, thirteen gas wells, and fifty-four dry holes. The Permo-Carboniferous basin of Maranhao and Piauhy has about 2500 ft of sediments. Carboniferous and Devonian beds occur in the Lower Amazon basin, and there may be 10,000 ft of sediments on Marajo island. The Cretaceous area of the Acre region may be of doubtful value, because work in Peru has indicated that the basement is uplifted, thereby reducing the thickness of the sediments. It is considered probable that Brazil will become an oil exporter. There is the possibility of obtaining oil from the Tertiary and Gondwana oil shales, and the Iraty shales possibly have the largest reserves.

Uruguay's oil possibilities are very slight. Argentina provides 40% of its own oil needs. The Comodora Rivadava fields gave 16,000,000 brl of oil from the Cretaceous in 1948, the Rhaetic basin of Mendoza 3,100,000 brl, the Jurassic province of Neuquen 2,700,000 brl, and Salta 1,000,000 brl. The Argentina reserves are estimated at 253–325 million brl. There are possibilities of expansion in area, and there are other prospects. Oil search in Paraguay has so far been unsuccessful, but Chile now produces at Cerro Manantiales. The oil is in the Jurassic.

Bolivia produced 463,500,000 brl in 1948 and consumed 442,885 brl. Venezuela produced 490,000,000 brl of oil in 1948 and Colombia 24,371,262 brl, the bulk being from the Middle Magdalena Valley in Colombia. Colombia has six oil provinces, and reserves estimated at 470–580 million brl. Considerable areas remain to be explored.

Ecuador produced 2,610,219 brl in 1948, mainly from the Eocene. The Oriente is being tested. Peru's output was 15,157,433 brl in 1948, half of which was exported. The Montana has 20,000 ft of Tertiary and Cretaceous beds; the extent of the underlying Permian is unknown. This area has considerable possibilities, but it is remote.

Oil exploitation is state-run in Bolivia and Chile. Argentina controls 60% of the production, and total nationalization is likely. Brazil does not allow foreign companies to hold concessions, but foreign co-operation may become necessary.

Legislation has created difficulties in Colombia. Peru has recently announced its plan to open the door to foreign as well as national operators. In Venezuela there is relative freedom of private enterprise and competition. G. D. H.

1391. 1949 in Venezuela. Anon. *Oil Gas J.*, 12.1.50, **48** (36), 42.—In one week of November 1949 Venezuela had a record producing rate of 1,476,009 b.d.

The Sibucara well has tested 8000–10,000 b.d. of 37° oil from the Cretaceous. It lies 9 km west of Maracaibo. The Ruiz field has eight wells and a potential of 4500 b.d. Freites, 20 km southeast of Cantaura, gives 32° oil. Further new fields are Abundancia (24°), Mapiri (30°), Piragua (41°), San Roque (38–48°), and Moriche (33–37°).

Venezuelan refining capacity was raised by 55,000 b.d., and an 18-in pipeline from Boscan to Lake Maracaibo was completed. G. D. H.

1392. Western Venezuela test approaching depth record. Anon. *Oil Gas J.*, 9.2.50, **48** (40), 58.—The Alturitas wildcat south of Machiques has reached a depth of 14,965 ft. CQ-1 in Trujillo is reported to have found good oil, and is testing at 1700 ft.

Senta 1, west of El Roble, has been abandoned at 11,401 ft. G. D. H.

1393. Flow markings, groovings, and intra-stratal crumplings as criteria for recognition of slope deposits, with illustrations from Silurian rocks of Wales. J. L. Rich. *Bull. Amer. Ass. Petrol. Geol.*, 1950, **34**, 717–41.—Definition and analysis of the shelf, slope, and bottom environments and of their characteristic sediments are followed by the discussion and analysis of the features of rocks, particularly in the British Isles, which are believed to be products of the slope environment.

Inter-stratal and intra-stratal contortions in sandy and silty beds in Wales and elsewhere suggest flowage while the sediments were still unconsolidated. The environmental conditions which seem best to explain these phenomena are shown to be those to be expected below wave base of a foreset slope.

The author makes an attempt to establish criteria by which rocks deposited in the slope environment can be recognized. E. N. T.

1394. The invertebrate fauna of the Pechelbronn beds. S. Gillet. *Rev. Inst. franç. Pétrole*, Mar. 1950, **5** (3), 77–88; Apr. 1950, **5** (4), 104–19.—Among the lakes in France at the end of the Eocene and beginning of the Oligocene only these in the Parisian and Alsace regions have thick salt accumulations or petroleum. There are signs of reduced oxygen in the waters, while salinity variations killed off the fauna in great masses. When evaporation exceeded the inflow of water, gypsum and salt were deposited. A subtropical vegetation is indicated with little change in climate during the suite of deposits in the Pechelbronn basin. The dolomitic zone has a fresh-water fauna with a more saline fauna at the top. The red-bed series is continental. The Lower Pechelbronn beds show alternations of brackish and almost fresh waters. At the top the salinity increases. The *Mytilus* beds of the Middle Pechelbronn point to higher salinity. The *Bryozoa* beds indicate slightly saline waters, and the same is true of the *Hydrobia* beds. In places fresh waters are indicated, and at the top there was higher salinity.

In the Upper Pechelbronn beds the petroliferous basin had high salinities, but to the north and south there were fresh-water fauna. There are beds of anhydrite and gypsum in the marls and sometimes salt.

The general indications are that in the Lower Pechelbronn beds *Limnea*, *Planorbis*, and *Eosphaeroma* were prominent, while *Mytilus socialis* and ostracods were abundant in the early part of the Middle Pechelbronn beds. Bryozoa then invaded the area, while in the upper part *Amnicola angulifera* and *Hydrobia hassica* were dominant, with *Cytheridea mulleri*. Only the lacustrine facies of the Upper Pechelbronn beds have an abundant fauna, and this is characterized by freshly appearing species of *Melanoides*.

The sediments are marly, except at the top of the Sannoisian, where *Melanopsis* and *Melania* abounded.

The characteristic fossils of the horizons are not necessarily the predominant forms. The fossils characteristic of the various levels are noted, and the species are described with an indication of the environment, and the stratigraphic and geographic ranges in some cases. Numerous fossils are illustrated, and a list of the wells studied is included.

The fauna shows a predominant influence of southern forms (Limagne and Gard), and in the upper beds the molluscan fauna is almost entirely of southern origin. In the middle beds northern influences are seen during the deposition of the Hydrobia beds. Western influences are insignificant, the only species common to the Paris lake are those met in almost all of the Oligocene lakes. Some species are common to the northwest (Isle of Wight).

Tables give the proportions of the individuals of different species and a comparison of the main Sannoisian lakes. G. D. H.

1395. Geology of the Georgsdorf (Emsland) field. H. Lögters. *Erdöl u. Kohle*, 1949, **2** (12), 537–44.—The length of the field in an east–west direction is 6 km and the width exceeds 2 km. In the east the reservoir rock becomes clayey and thin, and thus limits the field, but the complete extent in the west is not yet clear. Both north and south limits are fairly well marked. Total production from 1943 to August 1949 was 183,000 tons from eighty-three wells; monthly production then was 14,000 tons and was still rising. The field is now divided into five structural subdivisions, which are discussed in some detail, the tectonics now being much clearer as a result of the numerous wells drilled since 1947. From the regional viewpoint, the Georgsdorf structure is part of the series of folds of east–west strike which characterize the Saxon tectonics of West Emsland. The unusually strong folding, etc., which is seen in the detailed structure of the field may perhaps be ascribed to underlying salt beds which are present in the Munder Mergel (Portland) and which are well developed in the deeper part of the basin. S. E. C.

1396. Roumanian crude oils. H. Hlauschek. *Bull. Amer. Ass. Petrol. Geol.*, 1950, **34**, 755–81.—This is an endeavour to discover the relationship between the chemistry and geology of Roumanian crude oils, based on almost 300 Hempel analyses, which are presented in the form of tables and graphs.

It is concluded that depth and structure do not influence the chemical position of Roumanian crude oil. The Dacian crudes are mostly of naphthene and naphthene-intermediate base. The Meotion crudes, and the few small occurrences in the Miocene, are mostly of paraffin to intermediate base.

The Dacian oils originated in the Dacian or Upper Pontian, while the Miocene or Meotian oils originated in the Meotian, and the Oligocene oils in the Paleogene.

E. N. T.

1397. Description of the Moroccan oil accumulations in the order of their discovery. W. Bruderer. *Bull. Ass. franç. Tech. Pétrole*, (77), Oct. 1949, 3–28.—The Rharb and Phosphate basins and the Hahas trough lie completely within Morocco, while the Moulouya, Zis-C. Bécher, and Tindouf basins extend into adjacent territory. Only the Rharb basin has so far revealed indisputable oil shows, and all the fields are in this basin. In this basin the Palæozoic shield plunges northwards, and under a Miocene cover there are Trias, Lias, and Jurassic beds. Ain Hamra produces from Miocene sands. Bou Draa and Tselfat produce from Jurassic, Liassic, and Triassic beds on the limestone ridges enveloped by the Miocene or overthrust by the Cretaceous. In one place the basement immediately underlies the Miocene, and the Jurassic forms a belt around the basement high. Oued Beth lies on the edge of this high, and produces from the ancient schists.

The search for oil began in 1923 because of the Fokra seep a few kilometres from Ain Hamra. The first well on the presumed anticlinal axis gave 500–1000 litres/day from 140 to 200 m. Two wells drilled in 1929 were not commercial successes, but geophysical and geological studies confirmed the presence of an uplift, believed to be associated with a piercing Triassic salt series. Later wells showed numerous small Tortonian accumulations, and pointed to a complex structure. Wells with outputs up to 16 tonnes/day were completed at depths of 120–250 m. Light oil has been found in the Oligocene.

At Tselfat a number of holes were drilled near two seeps prior to 1930, and then detailed geological studies revealed a double fold overturned to the east and west. Two wells drilled in 1931 and 1932 produced from an upper Toarcian limestone. Fracturing was important. Variable amounts of salt water accompanied the oil, the best wells giving 5 tonnes of oil/day. In 1934 there was a blow-out of oil and water from the Domerian. Oil from the Triassic core of the fold is the same as that of the Domerian. The field is now exhausted.

Bou Draa is a faulted fold covered in the north by a Cretaceous overthrust. The first well drilled in 1935 gave oil from the Toarcian at about 250 m. In the central area outputs of 5–8 tonnes/day have been obtained at 200–250 m. The wells have declined rapidly because of lack of active water drive. Water injection has caused rapid rises in oil output.

Oued Beth was discovered in 1947, when oil was met in the base of the Miocene at 960 m. A later well obtained oil from schist below the Miocene, at a point near the margin of the Jurassic deposits. The oil lacks gas and light fractions; it is under water-drive. This oil is probably a remnant of former important oil accumulations, and was emplaced during tectonic activity. Further search will be made along the shore-line belt, and the future programme is intended to show whether the past discoveries represent the entire possibilities or whether there are more valuable accumulations.

A peak output of 5986 tonnes was obtained in 1941, and a further peak of 12,915 tonnes in 1948.

G. D. H.

Geophysics and Geochemical Prospecting.

1398. West Texas leads in regional geophysical activity. Anon. *World Oil*, 15.2.50, **130** (3), 61.—455 geophysical and core-drilling crews were operating in the U.S. at the end of 1949, compared with 559 at the end of 1948. West Texas was the most active area, having seventy-one geophysical crews and four core-drilling crews.

A table gives geophysical and core-drilling activity in the U.S. at the end of 1949 and 1948.

C. A. F.

1399. Radioactivity survey in Southwest France. E. N. Tiratsoo. *Bull. Amer. Ass. Petrol. Geol.*, 1950, **34**, 742–54.—The application of a new method of surveying in the elucidation of the geology of a particular area.

The radioactivity surface survey is valuable in the differentiation of sedimentary beds in areas where surface exposures alone are insufficient. It is most useful in delineating boundaries between different beds which are otherwise obscured, particularly when there is good lithologic contrast between the surface rocks and provided too many beds are not present in a small area. This technique, in which a highly sensitive battery-operated form of portable Geiger–Müller counter is employed, has the limitation that it can be used only in localities where the soil is autochthonus, but is otherwise claimed to be a very useful aid to geological mapping.

The author describes an investigation carried out by surface radioactivity measurements in southwestern France in one part of the Aquitaine sedimentary basin. In the coastal area between Biarritz and St. Jean-de-Luz, a plug of gypsiferous Keuper shale is exposed between the Senonian–Turonian Bidache limestone on the north and the Paleocene limestone on the south. A radioactivity traverse was made from Cap Martin to Guethary on this coast, and it is deduced from the results obtained that there is no evidence that the "ophite" outcropping at the Rochers de Peyerblanque is of the same age as the Keuper plug, as has previously been suggested. Furthermore, the Keuper plug showed a remarkably high radioactivity, which reached its peak about its geographical centre. Certain corrections in the accepted geological boundaries of the area are suggested. E. N. T.

1400. The recognition and evaluation of reflections. T. Krey. *Erdöl u. Kohle*, 1950, **3** (1), 14–16.—In seismic practice reflections of very varying quality can be recognized and the evaluation of the poorer ones is open to doubt. For that reason the author has calculated the probabilities of reflections being due to the chance appearance of factors such as phase equality, increase in amplitude, and decrease in amplitude, and as an example there is given the probability with which the chance appearance of phase equality and amplitude increase in five consecutive pendulums can be expected. If the probability is less than 10% the author considers he is dealing with a true reflection, from 10 to 50% the matter is doubtful, and for probabilities exceeding 50% evaluation is impossible S. E. C.

1401. Determination of true dip and depth of beds by reflection seismics. L. Krouskij. *Erdöl u. Kohle*, 1949, **2** (11), 489–90.—The most convenient arrangement for a reflection seismic profile is to set the shot point and observation points along the direction of dip. When nothing is known of the structure it is necessary first to determine true dip direction, and this is usually done by shooting "cross-spread," in which two lines are laid out approximately at right angles to one another. The calculations from the observations thus made are very complicated, and errors are difficult to trace, so the author has devised a graphical method, details of which are given. S. E. C.

Drilling.

1402. Cost investigation on water loss reduction. G. M. Graham. *World Oil*, Feb. 1949, **128** (10), 74.—A method is described whereby laboratory equipment may be used to simulate field conditions in order to determine the fluid-loss properties of drilling muds. Undesirable effects of high-water-loss mud are: (1) increased hole diameter in soluble zones; (2) hydration of formations; (3) thick filter cake; (4) water blocking, reduced permeability, etc.

Additives to improve water-loss properties must: (1) be effective in small quantities; (2) not impair control of drilling fluid; (3) be chemically stable at anticipated temperatures; (4) have no corrosive action on equipment; (5) be cheap, easily obtainable, and easy to store, handle, mix, etc. Such additives are gelatinized starch, sodium carboxymethylcellulose and oil-base stock. Of these, starch is the most widely used, cost and availability of carboxymethylcellulose have restricted its use. In this evaluation of the comparative effects of additives the following programme was adopted:—

(1) The apparatus approximated to field drilling conditions.

(2) A native-clay fresh-water drilling fluid was used, the viscosity, gel strength, density and pH being maintained by a common field method of chemical control.

(3) Water losses determined at the temperature of drilling fluid while drilling and differential pressure under well conditions.

(4) Total costs of water-loss reducing agent and of chemical control per barrel of fluid were determined.

(5) Costs to effect a given water loss for starch, carboxymethylcellulose and oil-base stock, with native-clay–fresh-water systems were determined. Methods of investigation are described and results tabulated and plotted. For the native-clay–fresh-water systems used it is concluded that : (i) water loss increases with temperature. (ii) Water loss increases with differential pressure. (iii) Starch and carboxymethylcellulose give similar reductions in water loss. Reduction in water loss is slight beyond a concentration of starch or carboxymethylcellulose of 1% by weight (4 lb/brl). (iv) Initial treatment with oil-base stock gives sharper reduction than starch or carboxymethylcellulose. Negligible reduction occurs after a concentration of 25% by volume of oil-base stock.

(6) For 25% reduction in water loss starch is most economical, emulsion least. For 50% reduction starch most economical, carboxymethylcellulose least. For 75% reduction, emulsion most economical, carboxymethylcellulose least.

(7) Max per cent reduction is obtained by using emulsion.

(8) In the case of prolonged contamination by calcium or salt, sodium carboxymethylcellulose is most economical.

In determining which agent to use other factors to be considered are, *e.g.* desired percentage reduction, effect of contamination, effect of agent on chemical control, etc.

References are appended. C. G. W.

1403. Drilling technology and its prospects. J. V. Pennington. *Petrol. Engr*, Nov. 1949, **21** (12), B-60.—A history of methods of making hole from antiquity to the present time. It is pointed out that long periods of time have elapsed in the past between the conception and practical application of new methods. The application of methods, techniques, and equipment in an advanced state of development in other industries, has been unnecessarily slow.

In an attempt to classify all the known techniques the following divisions were suggested : (1) type of energy supplied at the top of the hole ; (2) means for transmitting the energy to the bottom of the hole ; (3) means for converting one form of energy to another ; (4) means for applying the converted energy to the rock ; (5) incidental ideas. These are further subdivided and discussed. It is concluded that the major problem at present is that of transmitting energy down the hole. The author suggests that the techniques at present employed in the stone-working industries are among the most promising, if transmission problems can be overcome. C. G. W.

1404. New Drilling Methods and Equipment. E. C. Hellums. *Oil Gas J.*, 2.3.50, **48** (43), 50.—(1) Jet-type rock bits—three cone–three jet or two cone–two jet have been used successfully. The bit is claimed to drill 20–33% faster in broken and medium-hard formations. The principle has been applied to coring, using guide ribs for stabilization. A pack seals the space between the barrel and bit body.

(2) Charging mud-pump suction by use of a centrifugal pump is thought to increase life of valve seats, pistons, and liners, and give smoother operation.

(3) *Coil-type water-tube boilers.* A 300-h.p. boiler of this type will produce 20,000 lb of steam per hour at 500 p.s.i. and up to 500° F. Field tests are now being conducted.

(4) *Drill-pipe spinner.* An air-motor-powered spinner eliminates the use of the spinning chain.

(5) Propellor-type mud mixers, block deflectors, and automatic controls are also mentioned. C. G. W.

1405. Drilling activity in 1949 in N.W. Germany. W. Schott. *Erdöl u. Kohle*, 1950, **3** (1), 1–5.—Compared with earlier years, drilling in 1949 was very successful for not only were there several new productive wells in various structures but also the success of Scheerhorn I, between the Georgsdorf and the Adorf fields in Emsland, proved for the first time the presence of a stratigraphic trap in Northwest Germany. This

discovery of a deposit of a type hitherto not known there appreciably increases the chance of finding new reserves. The latter have increased from 7·8 million tons (proven and probable) in 1947 to 20·2 million tons in 1949, and this does not take into account important discoveries of the second half of that year. Emsland still accounts for 71% of the total.

A detailed account is given of drilling in Emsland, Schleswig-Holstein and Hamburg, East Friesland, Oldenburg and N. Hanover, the Hanover–Celle–Brunswick district, and Westphalia-Rhineland. S. E. C.

1406. Controlled and directional drilling. E. Nebe. *Erdöl u. Kohle*, 1949, **2** (11), 490–8.—Usually it is desirable that a borehole should be vertical, but experience shows that borings do deviate, and the reasons for this may be sought in the drilling method, weight on the bit, type of bit, rate of rotation, lithology, and inclination of the strata. Measurement of the deviation of a borehole from the vertical can be made by single-shot instruments or by multishot or multiple recorders. Accuracy of measurement depends on the characteristics of the instrument and the method of running it in the borehole. Directional measurements are not needed if the deviation does not exceed the critical angle of 2–3°. Some examples are discussed.

Directional drilling can have as its object correction of an inclined borehole, deviation for geological reasons, such as crossing a fault zone or moving from edge-water or gas cap into the oil zone, or avoidance of a topographical obstruction vertically above the objective. Small deviations are best obtained in very soft rocks by a hydraulic bit and in harder rocks by drilling off-centre with a pilot bit ; for greater angles a knuckle-joint or a removable whipstock should be used. The simplest method of orientation is to use the Eastman apparatus. The natural tendency of a boring to deviate up dip in preference to other directions should be taken into account when locating boreholes or setting whipstocks, for by this means the number of settings may be reduced. The maximum deviation should not be more than 1 in 5. S. E. C.

1407. Design of offshore drilling structures. A Symposium. *Oil Gas J.*, 23.2.50, **48** (42), 136–61.—Six articles are devoted to the effect of weather on offshore projects. Subjects covered include damage to offshore structures, new specifications and design problems, insurance on offshire risks, and oceanographic and meteorological factors in designing offshore structures. C. G. W.

1408. Wave forces computed for a typical offshore drilling site. P. L. Horrer. *Petrol. Tech.*, Dec. 1949, **1** (12), *A.I.M.M.E. Tech. Paper No.* 2767, 299–303.—Wave attack on offshore structures can result in severe damage, and therefore the forces which may arise from waves must be considered in designing drilling rigs for use in shallow water. Adequate strength must be provided, while unnecessary expense is avoided. By using wave data it is possible to predict the most suitable platform height, structure orientation, and expected wave forces. When wave records are not available a technique can be employed to derive information about wave characteristics from past meteorological observations and near-shore submarine topography. Poor design may lead to changes in bottom form near a structure. Round piling and bracing is better than I-sections. Network superstructure must be kept at a minimum.

Wave characteristics in deep water are obtained from weather maps ; the modification of the waves in shallow water is determined, and the characteristics of these waves provide the expected frequencies of forces and moments on engineering structures at the proposed location.

A series of tables and diagrams summarize the computations for frequencies of various wave heights and maximum frictional drag for a typical offshore drilling site.

G. D. H.

1409. New 8000 ft submersible drilling barge. L. S. McCaslin. *Oil Gas J.*, 9.2.50, 48 (40), 67.—Williams Drilling Co. is now using an 8000-ft submersible drilling barge with a 127-ft cantilever derrick. The barge is all welded 130 by 36 by 11 ft deep, with a drilling slot 8 by 65 ft. The hull contains six ballast and four fresh-water compartments, and draws 4–5 ft of water when floating. Two heavy-duty spud posts

29 ft by 17 in by 17 in each with hoists are built in at the forward end. The derrick has a capacity of 450,000 lb. A detailed list of equipment on the barge is given.
C. G. W.

1410. World's largest diesel electric drilling barge. Anon. *Oil Gas J.*, 9.3.50, **48** (44), 68.—This barge used in swamps and bayous was constructed from a war-surplus L.S.T. Dimensions are 212 by 50 by 20 ft, the rig generating 1800 kW. Features of the installation are: (1) the 136-ft portable derrick, which can be lowered in a few minutes, (2) all drilling equipment and crew's quarters on one barge, (3) can drill in 18 ft of water, (4) very short setting-up time, (5) bulk mud-handling system capacity from 10 to 300 sacks/hour. The system handles material by screw-type conveyor and air. Central control panel facilitates operation.

Equipment used on the barge is listed. C. G. W.

1411. Shell's marine rig No. 10. L. S. McCaslin. *Oil Gas J.*, 12.1.50, **48** (36), 54.—Complete equipment for drilling a 15000-ft well has been mounted on a converted L.S.T. craft. The craft is towed from one location to the next. Usual procedure has been to use L.S.T.'s in conjunction with stationary platforms, whereas this method gives a completely mobile unit.

The L.S.T. is 328 ft long, and a drilling slot 8 by 69 ft was cut in the bows of the craft. Procedure is to drive a string of surface casing and to sink and secure by piling a pontoon at the location. The pontoon fits into the slot of the L.S.T. Three 204-ft L.S.M.'s are sunk on the seaward side to act as breakwaters. These can be refloated and towed to a new location. Stability is achieved by flooding ballast tanks. To keep a close check on the stability list and trim, indicators are fitted and strain gauges placed on the turn buckles which tie down the blow-out preventer hook-up.

Major items of equipment are listed. C. G. W.

1412. Cheap fast electric logs. C. J. Deegan. *Oil Gas J.*, 9.2.50, **48** (40), 76.—Valuable information may be obtained by logging shallow " strut " tests and seismic shot-holes. An instrument has been developed to give self-potential and resistivity logs in holes up to 1500 ft deep. The instrument is designed to get a log of a 700-ft " strut " test in an overall time of 20 min. C. G. W.

1413. The Microlog. A new electrical logging method for detailed determination of permeable beds. H. G. Doll. *Oil Gas J.*, 2.3.50, **48** (43), 62.—The microlog has been developed as a means of determining the location of permeable beds. It has important applications in limestone, sand, and shale formations. A microlog is a log of resistivities recorded with electrodes spaced at short distances from each other in an insulating pad, pressed against the wall of the hole. Such a system measures the average resistivity of the small volume of material located under the pad. Two different electrode systems with different depths of investigation are used in combination to provide two logs recorded simultaneously. When the electrodes are applied to a permeable bed the resistivity measured by the short-spaced system is largely that of the mud cake. The resistivity by the longer spaced electrode system opposite a permeable bed will be greater than the resistivity measured by the short spacing. Such a difference, or departure, is called a positive departure, and a high degree of positive departure almost certainly indicates a permeable formation. In the case of beds of low, medium, and high resistivities and low permeabilities, the departures may be: (1) negligible, (2) appreciable, but resistivities will be greater than the limiting resistivity for permeable beds, (3) negative.

The construction of the equipment and the interpretation of the resulting logs is described and illustrated. References are appended. C. G. W.

1414. Lime base muds. J. L. Battle and P. E. Cheney. *Oil Gas J.*, 16.3.50, **48** (45), 81.—Available data on the use of lime-base muds is summarized and reviewed. A major difficulty in the early use of lime-base muds was the variable success of conversion from sodium to lime base. The development of a field method of estimating lime content of muds proved invaluable to the study of the muds. The estimation is based on difference between the alkalinity titration of the mud filtrate, and of the whole mud. Laboratory experiments on whole mud and filtrate alkalinities with

varying concentrations of lime and caustic were performed, and the results plotted. From these results a standard procedure for estimating lime contents was formulated. Theoretical considerations are discussed. References are appended. C. G. W.

1415. Chemistry and control of lime base drilling muds. A. W. McCray. *Petrol. Engr*, Nov. 1949, 21 (12), B-54.—Lime-base muds are muds in which some of the sodium ions adsorbed on to the clay particles are replaced by calcium ions. The major advantages of lime-base muds are: (1) will stand more contamination, particularly chloride contamination, than other muds; (2) can build up high weights.

The control of lime-base muds by the addition of caustic soda, dispersants, soda ash, and the maintenance of such systems, is described.

References are appended. C. G. W.

1416. A study of limed mud systems. W. C. Goins, Jr. *Oil Gas J.*, 19.1.50, **48** (37), 52.—Limed muds are basically natural shale muds with added barytes and bentonite and treated with organic thinner, starch, caustic, and lime. Advantages claimed for the systems are: (1) immunity from cement contamination, (2) greater toleration for dispersed shale before becoming viscous, (3) less gelation with salt-water contamination, (4) success in drilling heaving shale zones.

Normal fresh-water muds are usually changed to limed-mud systems after setting intermediate casing, in preparation for deep drilling, *i.e.*, at about 6000 ft. Usual procedure is to raise the pH to 11·5 or more with a caustic–quebracho mixture, and then make a pilot test to determine the necessary quantities of caustic, lime, and quebracho to give a low, workable viscosity and gel strength. The quantity of starch necessary to give low fluid loss is determined similarly.

The effects of lime addition to normal muds are usually ascribed to a conversion of a sodium-base clay or shale to a more inert calcium-base shale. It is pointed out that this explanation is inadequate.

Experimental results on the adsorption of calcium by bentonite in the presence of caustic soda, and the variations of viscosity of muds with various additives are presented graphically.

It is concluded: (1) that calcium adsorption is only a fraction of base exchange capacity, (2) that calcium adsorption is limited by the presence of caustic soda, (3) viscosity of limed muds depends on calcium-solubility, which is controlled by concentration of caustic, (4) when solubility is properly controlled, excess lime has little effect on viscosity, (6) that dissolved calcium is effective in inhibiting hydration.

Concentrations of dissolved calcium greater than about 200 parts per million or concentration of greater than 2% of sodium chloride give a maximum inhibiting effect. References are appended. C. G. W.

1417. Study of a high pH mud. E. Dutrieux and H. Tachet des Combes. *Rev. Inst. franç. Pétrole*, Apr. 1950, **5** (4), 120–2.—In North Africa two high pH muds have been used:—

(*a*) a red mud with pH about 11·5;
(*b*) a red lime mud with pH about 12·25.

Both can be used with or without starch. There is also a soda–lime–starch mud with pH 12·8–13.

While drilling OR1 a red mud with lime and starch was used, treated with soda and quebracho. It was found after a time that direct addition of lime without quebracho was effective. Later soda was found to give the same result as lime, though more strongly. This procedure gave a mud with zero gel strength, a Stormer viscosity of 30–35 cp, and a density of 1·35, and it kept barytes in suspension; the filtrate was 5·5 cc/30 min.

It was found that the quantity of lime which reduced the 10-min gel strength to zero did not affect the strength attainable in longer periods, but soda considerably lowered the latter values. Addition of soda after lime enabled the electric logs to be run to the bottom of the hole.

It is considered that the above type of mud is of value in drilling in marly rocks because the high pH precludes the taking up of more marl. The mud was successful in

drilling massive anhydrite and salt. There was a saving by the elimination of the use of tannin. G. D. H.

1418. Flow properties of drilling mud. T. H. Dunn, W. F. Nuss, and R. W. Bock. *World Oil*, Feb. 1949, **128** (10), 85.—Present data is not sufficient to enable the fundamental theory of plastic flow to be applied generally to drilling-fluid problems. The nature of plastic flow is described and equations derived. An approximate equation is

$$\Delta P = \frac{Lty}{27D} + \frac{32uVL}{gD^2}$$

where D and L are dia and length of pipe,

ΔP = pressure drop,
V = fluid velocity,
ty = yield value (value of shearing stress at which flow commences),
u = rigidity (slope of the plastic curve).

In order to determine the mud-flow constants for use in plastic-flow equations, a rotary viscosimeter was developed. The instrument was calibrated using fluids whose flow constants had been determined in pipe-flow systems. Flow constants were obtained for each of seven muds and flow curves computed using the equations previously developed and presented.

For field use a viscosimeter was constructed of the funnel type. Flow curves obtained by this means are correlated against rotary viscosimeter results. The practical applications of such data are illustrated by several examples. C. G. W.

1419. Practical treatment of clay type drilling muds. S. Harris. *World Oil*, Mar. 1949, **128** (12), 79.—A programme for testing and controlling drilling muds is outlined. The measurement and control of the following variables are described: (1) viscosity; (2) gel strength; (3) mud density; (4) sand content; (5) filtration loss; (6) pH.

Proper use of the measuring instruments and available means of control of variables is discussed.

A practical method of pilot testing drilling muds at the well is given.

References are appended. C. G. W.

1420. Clay in the petroleum industry. J. Endell. *Erdöl u. Kohle*, 1950, **3** (3), 105–9.—The definitions of clays and clay substances by the German Ceramic Society are given, and the state of the clay minerals, especially their external characteristics, are discussed. Clays are used in drilling muds, in oil-well cements, and for decolorizing oils. The natural drilling muds of North Germany are shown by X-ray analysis to consist mostly of kaolinite and micaceous-type clay minerals which have not the high swelling capacity and ability to retain water of the bentonites. These muds therefore tend to be much too heavy and viscous and to give a very thick filter-cake. Clay is added to oil-well cements to improve the plasticity of the slurry and decrease shrinkage, and for this purpose bentonite is again the best.

Both artificially activated bleaching earths and other natural substances with large surface areas are used for decolorizing oils. Artificially activated earths are produced from bentonite by acid treatment, which gives a very porous structure and replaces the exchangeable cations by hydrogen. Bleaching, therefore, can be explained by adsorption and chemical reaction with the hydrogen ions on the clay surface. In a natural American fuller's earth the clay mineral is attapulgite, which is fibrous; the other clay minerals are platy. S. E. C.

1421. Action of phosphates on kaolin suspensions.—J. R. Van Wazer and E. Besmertnuk. *J. phys. & colloid Chem.*, 1950, **54**, 89–106.—The deflocculating action of vitreous phosphates on clays used in drilling muds is well known. Rheological data on some of the various kaolin–phosphate–water systems is reported, and the observations are interpreted in terms of the structure of phosphates and of clays. Attempts

are also made to explain the mechanism of the plasticity observed in clay–water systems. D. F. J.

1422. Mud pump selection. H. L. Willke. *Petrol. Engr*, Dec. 1949, **21** (13), B-32.—See Abstract No. 433. C. G. W.

1423. Accelerated mud filter press for field testing. V. B. Zacher. *Petrol. Engr*, Nov. 1949, **21** (12), B-50.—The need for a mud filter-press, for making tests on a rig, has been accentuated by the tendency towards deeper drilling. A simplified portable filter-press has been constructed for this purpose. The instrument consists of a chromed cylinder $3\frac{1}{2}$ in dia with a wheel on one end and spout on the other. A flanged neoprene bag 500 cc capacity, held in the main cylinder, receives the mud to be tested. The flange, to which screen, filter-paper, and lid are attached, forms the top gasket and contains a slot, making a self-sealing lid. At the other end are three compressed springs, the energy of which expresses liquid from the mud. Calibration of the springs is used to indicate pressure. The springs are compressed by a hand-wheel through a train of gears. Collection of filtrate in a filtrate receiver indicates fluid loss. C. G. W.

1424. The time factor in cementing. B. Barkis. *Oil Gas J.*, 12.1.50, **48** (36), 74.—A time study of cementing operations was made to determine : (1) the time required for each phase of the job ; (2) whether any savings in time might be made ; (3) the effect of delays or stoppages of casing movement on the success of the job.

The phases are as follows :—

(1) Laying down drill pipe as the drill string is pulled for the last time before running casing.

(2) *Scratcher Installation.* This is undertaken while the mud is being conditioned preparatory to running casing. Good planning and a fast welder will cut welding time by 50–60% during this phase.

(3) *Rigging-up to run casing.* Close supervision during this period will reduce breakdowns and delays in running.

(4) *Running casing.*

(5) *Circulation and movement of casing.* Improvements in connecting cementing lines, installing cementing head, and releasing cementing plugs are necessary to reduce the incidence of frozen strings.

(6) *Mud circulation.*

(7) *Mixing cement slurry.* Increased mixing rates speed up the whole cementing operation, and also tend to prevent the formation of air pockets in the cement slurry.

(8) *Installing the plug.* The use of a plug-retainer-type cementing head enables the plug to be released without opening the casing, while keeping the casing in motion. This prevents admission of air to the casing, and reduces the possibility of the casing freezing.

(9) *Pumping down.* It is concluded that no large savings can be made in rig time, but that the saving of a few minutes during the critical period when the casing reaches bottom, and later as the cementing plug is released, are of extreme importance. The importance of planning cementing programmes is emphasized. C. G. W.

1425. Multi-stage cementing in the Permian basin. R. D. McBrian. *World Oil*, Mar. 1949, **128** (12), 87.—Formation characteristics in the Permian basin make multi-stage cementing desirable in order to conserve oil and gas zones and prevent corrosion of well casings. Attempts to cement in one stage may lead to breakdown of one or more zones, and loss of returns by formation of cavities in the underlying salt beds.

The usual method of multi-stage cementing has been to cement as much as the formation can stand, then perforate above the top of the cement and re-cement. The expense and uncertainty of the method make it undesirable.

Multi-stage cementing equipment enables convenient cement stages to be chosen with the casing centralized at desired points. Uniformly spaced parts and the use of down whirler ports give increased possibility of uniform cement column. Limitations and applications of the method are described. C. G. W.

1426. New medium rig features mobile console control unit. R. F. Carlson. *Oil Gas J.*, 16.2.50, **48** (41), 90.—This rig has a 129-ft mast and draw-works capable of handling 10,000 ft of 4½-in drill pipe. All control equipment is pneumatically operated from a console control unit. Draw-works are compounded for operation from either or both of two twin diesels with fluid couplings. Rotary table driven by propellor shaft.
C. G. W.

1427. Portable pipelines simplify wildcat water and fuel supply problems. G. M. Wilson. *World Oil*, Feb. 1949, **128** (10), 71.—A company has been supplying rental pipelines for water and fuel for wildcat operations. Lines are lightweight, grooved end, and quick coupling in 2, 3, and 4 in dia. The pipe is handled in 40-ft lengths. Equipment used consists of truck and trailer for hauling pipe to the job, and a four-wheel-drive truck equipped with a small boom and front-end winch. In rough country pipe has been handled by hauling and pushing 1000-ft lengths across country. Pushing was found more successful in semi-mountainous conditions. C. G. W.

1428. Causes and prevention of drill pipe and tool joint trouble. 5. H. G. Texter and R. S. Grant. *World Oil*, Feb. 1949, **128** (10), 96.—The two major problems of the present day with tool joints are wobble failures and wear on the outer surface of the joints.

Conditions tending to increase wobble failures are : less drilling weight, and use of cut-friction bearings resulting in less torque tending to tighten loose joints, and in conditions favourable for the occurrence of transverse vibrations tending to loosen joints. Higher rotary speeds increase vibration and whipping of the pipe, and higher mud pressures tend to cause mud cutting or lapping of loose joints. The manner in which wobbling can cause joint failures and methods for avoiding such failures are described.

Failure by longitudinal splitting of tool joints and by galling threads are also dealt with. C. G. W.

1429. Causes and prevention of drill pipe and tool joint trouble. 6. H. G. Texter and R. S. Grant. *World Oil*, Mar. 1949, **128** (12), 106.—This, the last of the series, deals with wear on the outside of tool joints. Practical methods of combating this are : (1) use of oversize tool joints ; (2) development of shrunk-on tool joints ; (3) use of wear subs between tool joints ; (4) use of hard-faced tool joints ; (5) use of long strings of drill collars.

Corrosion fatigue failures in tool joints are briefly dealt with. Approved practices which minimize damage to, and consequent trouble with, tool joints are listed. A discussion is appended. C. G. W.

1430. Hydraulic torque converters and fluid couplings for oil field machinery. Part 3. H. A. Davis. *Petrol. Engr*, Nov. 1949, **21** (12), B-36.—In this, the last of the series on hydraulic couplings, the applications of hydrokinetic types to oilfield machinery are discussed.

(1) *Schneider Torque Converter.* Application has been limited due to unavailability in an adaptable form. Two actual applications are described. Advantages are : (*a*) maximum stall torque multiplication of 3 : 1 is available in converter drive ; (*b*) when output torque is unity or less operation is in efficient range with output speed approaching input speed ; (*c*) can be used for side-output drives without using an outboard bearing device.

(2) *Lysholm–Smith Converters.* This type has an extensive and varied application. Their application to : (i) light servicing hoists, (ii) clean-out rigs, (iii) heavy-duty rigs, (iv) independent rotary drives, and (v) converter pump drives is described and illustrated. C. G. W.

1431. A casing recovery technique. E. E. Embury. *Petrol. Engr*, Nov. 1949, **21** (12), B-18.—Casing has been recovered from a well without disturbing the production capacity. Three strings of casing had all been landed at the surface. The inner casing was parted at 3000 ft, and having determined that the stub was belled satis-

factorily, the intermediate string was cut at 2490 ft. A tapered adapter was set at this point. To shut off a leaking section the following procedure was adopted. A shoe with a babbit insert in the base was fitted to a 900-ft sleeve. At the top of the sleeve two double-cup packers, the upper faced down, the lower faced up, were fixed. This sleeve was then run to seat on the stub of the original inner casing. The repair was effective and 4600 ft of casing salvaged. C. G. W.

Production.

1432. New production methods and equipment. Anon. *Oil Gas J.*, 2.3.50, **48** (43), 54.—(1) A one-well cycling programme enabled a lease to produce condensate over a period of years when the lease would otherwise have been lost because of no production. The well was dually completed in the gas cap of two sands, and gas produced through the tubing, stripped and re-injected through the casing.

(2) *Micrologging pay sections.* The microlog uses electrical contacts with spacings narrowed down to 1 and 2 in. This makes it possible to measure the resistivity of the mud cake. The mud cake tends to build up on porous sections, and these sections are thus shown on the microlog.

(3) A hydraulic fishing tool is described which enables a fish, once engaged, to be jacked gradually up the hole without exerting an excessive pull on surface equipment.

(4) The hydraulic hoisting rig recently developed seems to be particularly useful for workover jobs.

(5) The application of purger chokes for reducing gas–oil ratios, of heat exchangers for positive chokes in gas-lift operations, and of a combination bottom-hole choke and gas separator are also described. C. G. W.

1433. Problems in secondary production methods. W. Rühl. *Erdöl u. Kohle*, 1950, **3** (2), 57–61.—Primary production, in general, removes only 20–40% of the oil in a reservoir, and so in Germany, for instance, where on that basis one must reckon with 35 million tons of oil remaining in the ground, the problem of reserves is one of improved recovery as much as of more intensive exploration. New fields require different handling to old, and technical control must be closer when dealing with well-depleted reservoirs which are usually very permeable. Optimum total depletion is to be expected when secondary production methods are applied to highly porous and permeable reservoirs before the primary stage is completed. A controlling factor, however, is the price of crude oil.

Choice of method depends on factors such as the petrography, structure and tectonic position of the deposit, energy relationships, degree of depletion, availability of injection media, presence of suitable boreholes, and the need for new drilling, etc. Tectonics play an important part in the German salt-dome fields, but experience shows that individual structural units in a field can be suitable for secondary recovery methods, especially for gas re-pressuring. In the German fields there is usually sufficient salt or fresh water for flooding, but gas in large quantities is difficult to obtain and air is frequently used instead. Gas re-pressuring is better for deposits already much depleted, for coarse-grained sands, and for rocks with a high connate water content. Water flooding is the better method when the oil content is high, the rocks fine-grained, and the connate water content low. Insufficient is known about chemical additives and the effect of high temperature, both of which can most easily affect the forces retarding fluid movement and promote considerable increases in depletion.

Research is concerned with core recovery, analyses, and interpretation; electrical and radioactive borehole measurements; distribution of the reservoir contents at the beginning of secondary recovery; correct spacing and arrangement of boreholes in relationship to the need for new drilling; the value of aids to increased flow, such as shooting, acidizing, selective shut-offs, etc.; pre-determination of injection pressures and quantities; increasing the effectiveness of water floods by surface-active chemicals; the pros and cons of air and other gases as substitutes for natural gas; recognition and prevention of slip and channelling; economics of each secondary recovery method.

The achievements in Germany and the rest of the world in the application of secondary recovery methods are summarized. S. E. C.

1434. Acidization in the Permian basin. W. R. Weaver. *Oil Gas J.*, 9.3.50, **48** (44), 73.—The most widely treated zones in the Permian basin are limestone and dolomite. Fields and zones treated are tabulated. Types of acid may be classified into: (1) regular inhibited 15% impure hydrochloric, (2) additive chemical, *e.g.*, low-surface-tension additive, emulsion preventative, and mud acid.

Undesirable effects following on acid treatment are: (1) formation of oil–acid emulsions, (2) placing a water block in the formation, (3) dissolving material which may be reprecipitated. Strong acid is preferred to weak acid, and where the expense is justified intensified acid may be used. This is the normal hydrochloric acid base with hydrofluoric acid and ammonium chloride. Such acid speeds up rate of reaction, dissolves more magnesium carbonate, and increases the permeability of the mud cake. Experience with inhibitors and normal acidization methods are described. The value of selective treatments is mentioned, and practices in blanketing, and in acidizing limestone and dolomite formations containing silicates are dealt with. C. G. W.

1435. New insert-type oil well pump undergoing tests. C. M. Davis. *Oil Gas J.*, 16.2.50, **48** (41), 108.—Pump parts have been standardized so far as possible. 300–400 successful installations have been made handling oils from 8° to 45° A.P.I. gravity. In this pump the travelling valve is located on the travelling barrel, thus permitting a larger valve system. A top-lock on pump maintains a top seal, protecting pump parts susceptible to abrasion. It is claimed that wear is practically negligible and that sanding up is eliminated. This type of pump is particularly susceptible to gassing, and gas anchors are essential where gas is present.

Operation of the pump is described, and field performance data are presented.
C. G. W.

1436. Some theoretical aspects of cycling. M. Muskat. *Oil Gas J.*, 19.1.50, **48** (37), 55.—This is the first part of a paper dealing with special aspects of cycling condensate reservoirs. Topics dealt with in this part are:—

(1) *Cycling pattern development.*—Pattern efficiencies may be determined by calculation or by a potentiometric model. For most practical applications the latter is more suitable. Such models should simulate the mD/ft contour of the reservoir or where this is not possible, should follow the isopach map of the reservoir. In practice, pattern studies must be made when only one or two wells are completed, and it may be necessary to assume reservoir uniformity in order to calculate well patterns.

Areal sweep efficiency increases with increased separation between injection and producing wells independent of the geometry of the reservoir. This indicates that end-to-end patterns for asymmetric and radial patterns for more symmetrical reservoirs will be most efficient. A pattern of one central injection well, with eight producing wells spaced uniformly around the circumference, gives a sweep efficiency of 80% with a uniform reservoir.

Whenever the pattern or reservoir becomes complex, potentiometric models are necessary for cycling studies. Moreover, with such models, it is possible to allow for changes in production or injection rates, and the conversion to injection when dry gas breaks through.

2. *Non-uniform permeability.* Quantitative analysis of non-uniform reservoirs can be carried out only by making extreme simplifying assumptions. The major assumption in such analysis is that the producing section is comprised of a sequence of layers differing from each other only in passing from layer to layer. This implies that fluid motion under steady state conditions will be parallel to bedding planes without cross-flow. In practice, it is impossible to predict between the degree of equivalence between assumed and actual flow, nor how average permeabilities for the streamline stratified system correlate with individual permeabilities determined from cores.

Accepting this assumption, the layers are arranged in a continuously increasing or decreasing order of permeability. Permeability distributions are expressed by analytical expressions. Three types of such distributions are linear, exponential, and probability distributions which may be described by the following equations:—

$$k(z) = k\text{min.}\,[1 + (r - 1)z/H]$$
$$k(z) = k(\text{min})r^{z/H}.$$
$$\frac{dz}{d\Phi} = \frac{H}{\sigma(2\pi)^{1/2}}\,e^{u}$$

where
$$u = -\frac{\Phi^2}{2\sigma^2}$$
$$\Phi = \log\frac{k}{k_s}$$

H = total thickness of the producing section
z = depth along well bore from layer of lowest permeability (when in order of increasing permeability)
k min = min value of permeability
r = ratio of max to min permeability
k_s = permeability of max probability,
σ = standard deviation.

Results of detailed analysis of cycling performance in these types of stratified formation are given in graphical form. A brief discussion of the results for each type is given. In order to apply the equations and resulting graphs it is necessary to determine which type most closely approximates the reservoir characteristics. This may be done by plotting in a sequence of increasing permeabilities the values as measured on core specimens.
C. G. W.

1437. Flowline paraffin removal. D. H. Stormont. *Oil Gas J.*, 16.2.50, **48** (41), 91.—A valve has been developed by means of which the oil production can be switched to a built-in by-pass, while a plug is inserted into an aperture in the valve plug. When the valve is in the " on " position the plug moves into the flowline and pushes soft paraffin deposits before it. The plugs are soluble in crude oil. The method will not clear heavy deposits of paraffin. C. G. W.

1438. Dynamometer charts and well-weighing. L. W. Fagg. *Oil Gas J.*, 12.1.50, **48** (36), 65.—A polished rod dynamometer may be used for measuring loads, torque, and horse-power on pumping units. The dynamometer card is a record of the resultant of all stresses in the polished rod throughout a cycle, and effective use of the dynamometer demands proper analysis of the resultant.

Dynamometer cards may be used to obtain : (1) information as a basis for the design of new installations, (2) factual data for analysing equipment failures, (3) information necessary for proper control and efficient pumping operation. Manipulation of the dynamometer for checking operation, and the method of determining the degree of counterbalance are described. Dynamometer cards typical of various pumping problems are shown and analysed. C. G. W.

1439. Some theoretical aspects of cycling. M. Muskat. *Oil Gas J.*, 2.2.50, **48** (39), 53.—Two further subjects are dealt with in this part of the paper.

(1) *Retrograde condensation about the well bore.* Even with complete pressure maintenance, the pressure draw-down required for gas withdrawal will result in retrograde condensation about the well bore. Condensation will continue, and when a saturation point is reached, excess condensate will be swept into the well bore. As production continues the radius of saturation will increase, resulting in increased losses of condensate. The magnitude of the losses may be calculated by the following equation :—

$$\frac{d\rho}{dt} = \frac{k/\mu}{4fr^2p}\cdot\frac{(pe^2 - p_\omega^2)^2}{(\log r_e/r_\omega)^2}\cdot\frac{dC}{dp}$$

where
ρ = condensate liquid saturation at time = t and radius = r,
p = pressure at radius r,
c = liquid content of reservoir vapour per unit volume,
f = sand porosity,
μ = wet gas viscosity,
k = effective permeability,
p_e, p_ω = boundary pressures,
r_e, r_ω = external and well radii respectively.

In order to apply this equation extensive data on the reservoir and on the fluid properties are required. An example of the application of the equation is given. It is concluded that losses from this cause are not likely to be of major importance.

(2) *Differential depletion.* Depletion operations lead to the development of different pressures and different degrees of recovery from regions of different permeability. Any form of analysis of this problem requires the use of extreme simplifying assumptions. In the treatment here given the system is assumed perfectly stratified with no cross-flow and a permeability distribution of an exponential type. It is further assumed that during pressure depletion the wells are operated with zero bottom-hole flowing pressures. The following equations are derived :—

$$\frac{\partial p}{p_1} = \frac{(r - r^{\partial u/u})\,(r^{\partial u/u} - 1)}{(r - 1)\,r^{\partial u/u}}$$

where p_1 = initial pressure,
$\partial u/u$ = fractional cumulative withdrawal,
r = stratification constant.

$$\frac{Q}{Q_0} = \frac{1}{r^{\partial u/u}}\left[\frac{r - r^{\partial u/u}}{(r-1)(1 - \partial u/u)}\right]^2$$

where Q/Q_0 = ratio of actual production capacity to that if the pressure were strictly uniform.

Plates of these two equations are presented. An approx treatment of the effects of cross-flow is also developed. C. G. W.

1440. Casing leak problems. H. N. Lyle. *Oil Gas J.*, 9.2.50, **48** (40), 78.—Casing failure may occur in a number of ways. Running of damaged or faulty pipe, weak sections damaged during cementing, and excessive wear by drill-pipe tubing or by fluid erosion are major mechanical causes. Corrosion and electrolytic action are also important.

Fishing, particularly for tubing, is common sequal to casing repair jobs. Methods of recovering stuck tubing and drill pipe are discussed. Two references are appended. C. G. W.

1441. Calibration of capillaries for permeability apparatus. J. W. Young, H. M. Millett, and A. G. A. Pierce. *Petrol. Engr*, Feb. 1950, **22** (2), B-45.—Measurement of gas flow is necessary for permeability measurements. A method of calibrating capillary or orifice flow meters is described. Flow in a capillary tube may follow a viscosity equation, an orifice plate equation, or a transition range between the two. In the latter case calibration over the whole range is necessary.

Capillary flow meters have been used wherever possible in preference to orifice flow meters. Temperature effects in the viscous region are marked in capillary meters, but the temperature corrections are eliminated in the calculation of permeability.

Poiseulle's equation for viscous flow in a capillary can be reduced, for any one instrument, to :—

$$\frac{Q}{T} = \frac{C \,.\, M}{Z}$$

where $\frac{Q}{T}$ = gas flow rate [ml/sec],
C = instrument constant,
M = differential pressure on the manometer,
Z = viscosity of air (centipoises).

Permeability may now be expressed by

$$K = \frac{1000C}{A^2} \times \frac{2P_2MV}{P_1^2 - P_2^2}$$

where A = area of core (sq. cm.),
V = volume of core (cc),
P_1 and P_2 = input and output pressures (atm).

For cores prepared from a calibrated core drill A will be constant and $\frac{1000C}{A^2}$ = constant.

Hence nomographs may be constructed and used for the calculation of permeability.

In calibration, air at constant pressure is blown through the capillary. The flow rate is measured by a manometer. Volume of gas is measured either by a wet test meter or by an endiometer burette. Temperatures at three points are recorded and times measured with a stop watch. Volumes are corrected for barometer, temperature and water vapour. Results are plotted differential pressure against flow rate, and when plotted on log–log scales give substantially straight lines. C. G. W.

1442. Producing oil wells affected by natural water drive. S. F. Shaw. *Petrol. Engr*, Nov., **21** (21), B-7.—Many wells are affected to some extent by natural water drive. A time is eventually reached when artificial recovery methods must be applied. Restricted production practices will increase the time for which natural drives may be used, and the application of artificial floods and pressure-maintenance methods in early stages will give high production rates with but small loss of reservoir pressure.

When artificial lifts become necessary one of the following methods may be used : (1) jack pumps centrally operated, (2) individually operated beam pumps, (3) submerged electrical centrifugal pumps, (4) gas lift or air lift.

The history of the gas-lift method is described. Major problems with the method are : (1) cheap source of high-pressure gas, (2) satisfactory disposal of large quantities of salt water.

Selection of the best method of operating a gas-lift installation depends on :—

(1) Selection of proper size of pipe through which to produce the oil–water mixture. This must generally be based on previous experience.

(2) Method of starting the well. Usual method is to use kick-off valves installed in the tubing. Alternatives are to use orifices in tubing couplings or to inject water or oil with the gas.

(3) Methods of carrying on operation. C. G. W.

1443. Problems of water injection in wells and corrective methods. Part I. Chemical problems in water flooding. L. C. Case. *World Oil*, Feb. 1949, **128** (10), 150.—Water injection may be used for the purpose of disposing of water produced with oil, or for maintaining reservoir pressure or both. Chemical problems associated with injection, other than those of corrosion or of wetting properties, are mainly problems of reaction leading to precipitation and consequent plugging of producing channels.

Salt water is generally found to be better for injection than fresh, since the latter may cause hydration and swelling of shales and clays within the producing formation. Mixing of two or more brines may cause precipitation, and formation and injection waters should be analysed before embarking on a project so that any treatment necessary to prevent plugging can be performed before injection.

The need for a thorough study of all aspects of a project is emphasized. Field examples of problems indicate necessary treatments and procedures generally adopted.

References are appended. C. G. W.

1444. Problems of water injection in wells and corrective methods. Part 2. Chemical problems in salt water injection. L. C. Case. *World Oil*, Mar. 1949, **128** (12), 142.—Practical examples of problems occurring in salt-water disposal systems are described. The manner in which such problems are solved and in which difficulties can be avoided is outlined. References are appended. C. G. W.

1445. Fundamental forces involved in the use of oil well packers. J. C. Webber. *Petrol. Tech.*, Oct. 1949, **1** (10), *A.I.M.M.E. Tech. Paper No.* 2710, 271–8.—An oil-well packer is a device for blocking the passage of fluids in an annular space, and in the cases discussed this is the annular space between the tubing or drill-pipe and the casing. In the conventional type slips on an anchor pipe below the packer cause the weight of the tubing on which the packer is run to expand the packing element. Thus the packer holds only so long as there is an excess downward load. Universal packers have slips above and below the packing element, and so these resist movement either

upwards or downwards after setting. Buoyancy and friction between the tubing and casing affect the effective load due to the tubing, while temperature and pressure changes also have their influence.

The forces acting on packers are analysed for various conditions, and a series of cases are examined in detail. Partial filling of the tubing will reduce the pull needed to release the packer, a principle which is applicable whether a circulating valve is present or not. G. D. H.

1446. Shooting in water flooding. S. T. Yuster. *World Oil*, Feb. 1949, **128** (10), 121.—To increase the efficiency of oil recovery, particularly in the case of secondary recovery methods, shooting is often employed. Investigations on shooting chiefly measure the shattering and caving tendencies of the formation and do not apply to problems of well flow. A method has been described which, within certain limitations, may be used to calculate the effective radius of a shot well.

Investigations of the effect of shooting upon spacing indicate that the gross profits in a recovery operation are considerably greater with shot than with unshot wells. The effect of shooting on ultimate oil production is unknown, but an analysis presented indicates that shot developments would still give greater gross profits.

The conditions under which corrective shooting, *i.e.*, shooting to correct heterogeneous permeability, may be used, are described. A method for calculating the effective well radius of a shot well is given, and an attempt is made to make a statistical study of the problem. The absence of extensive field data is responsible for poor correlation. Equations are derived relating effective radius distribution and shell size, to permeability.

The effects of multiple shooting, tamping, etc., are described, and the necessity for extensive investigations on a smaller scale is emphasized.

References are appended. C. G. W.

1447. Indiflux.—A new method of testing fatigue in sucker rods. D. H. Stormont. *Oil Gas J.*, 16.3.50, **48** (45), 84.—It is claimed that this method determines the relative amount of fatigue in sucker rods, and also shows variations on grain structure resulting from heat treatment. The test is based on correlation between physical and magnetic properties of the steel. As rods are pulled from the well they are de-gaussed and drawn through an air-core transformer, thus forming the core of the transformer. Alternating current through the coil magnetizes the rods as they are drawn through the coil, and the inductance of the transformer indicates the magnetic properties of the rods. Instruments are calibrated by sections of known magnetic properties. Method of operation and the interpretation of results are described. C. G. W.

1448. Care and use of sucker rods. J. S. Fuller. *World Oil*, Mar. 1949, **128** (12), 129.—Damage to sucker-rod strings, and the cost of pulling jobs as a result of premature failure of a sucker-rod, are of considerable importance.

Premature failure of rods is often caused by careless handling and storage of rods. Nicks and small cracks are areas of high stress concentration and are particularly susceptible to corrosion leading to early failure.

Practices resulting in increased life and better service from sucker rods are outlined and recommended. C. G. W.

1449. Production data study of an underground gas reservoir. L. C. Dickey. *World Oil*, Mar. 1949, **128** (12), 134.—The suitability of depleted gas fields for use as gas reservoirs is studied, with particular application to the Greenwood natural gas reservoir near New York. Factors affecting the suitability of such reservoirs are: (1) proper location in relation to gas-distribution requirements; (2) adequate structural closure of the reservoir; (3) sufficient volumetric capacity to warrant capital investment; (4) sufficient permeability to enable high injection and withdrawal rates to be maintained over extended periods; (5) production history should be available; (6) extensive data on the reservoir are necessary.

In the case of the Greenwood reservoir the analysis of the original gas was assumed similar to gas produced from a nearby field. The original reservoir volume was calculated from production data available during the producing life of the well. The

effect of water encroachment on reservoir volume is also evaluated. The application of this data to the use of the field as a gas reservoir is described. C. G. W.

1450. Calculating the clogging of sand filters and of oil-bearing strata. Yu. M. Shekhtman. *Izvest. Akad. Nauk S.S.S.R.; Otdel. Tekh. Nauk*, 1950, 346–56.—A mathematical treatment of the flow through a homogeneous sand layer of a fluid containing solid particles in suspension. A fundamental equation for the filtration of dilute suspensions is derived, and the application of this to water-flooding problems in the secondary recovery of pet is discussed; *i.e.*, in determining the extent of freedom from suspended particles required in a water to enable water-flooding operations to be carried out at the required rate for a given time without exceeding a permissible pressure. V. B.

1451. A firm solution of the problem of the filtration of dilute suspensions. Yu. M. Shekhtman. *Izvest. Akad. Nauk S.S.S.R.; Otdel. Tekh. Nauk*, 1950, 481–8.—An expansion of the previous treatment (see preceding abstract). V. B.

1452. Shot hole clearance improves oil recovery. F. R. Cozzens. *World Oil*, Mar. 1949, **128** (12), 154.—Oil production from a shot well is impaired by the accumulation of sludge, silt, etc., in the well bore and shot hole. If wells are not maintained in good condition permanent damage to the well may occur. To avoid expensive workover jobs it is recommended that wells be treated by light shooting, or acid treating, whenever any floating residue appears in the pumped oil. C. G. W.

1453. The application of the Laplace transformation to flow problems in reservoirs. A. F. van Everdingen and W. Hurst. *Petrol. Tech.*, Dec. 1949, **1** (12), *A.I.M.M.E. Tech. Paper No.* 2732, 305–24.—Solutions for the "constant terminal pressure case" and "constant terminal rate case" have been developed for the unsteady flow equation $\frac{\partial^2 P}{\partial r^2} + \frac{1}{r}\frac{\partial P}{\partial r} = \frac{\partial P}{\partial t}$. In the former case the terminal boundary pressure is lowered by unity at zero time and maintained constant, while the cumulative flow across that boundary is computed as a function of time; in the latter case unit flow across the terminal boundary operates from zero time, and the associated pressure drop is computed as a function of time. Extensive tables have been prepared for these two cases, both for finite and infinite reservoirs, and these can be used to reproduce the effects of any pressure or rate history met in practice.

The principal device used in the obtaining of the solutions has been the Laplace transformation, which has provided a simpler analysis than the previously employed mathematical techniques.

The Laplace transformation has also been applied to the analysis of flow tests. G. D. H.

1454. The relation between electrical resistivity and brine saturation in reservoir rocks. E. F. Dunlap, H. L. Bilhartz, E. Shuler, and C. R. Bailey. *Petrol. Tech.*, Oct. 1949, **1** (10), *A.I.M.M.E. Tech. Paper No.* 2711, 259–64.—The resistivity of various sectors of small cores has been measured at different brine saturations attained by desaturating the core by the capillary-pressure technique. Details of the experimental technique are given. Some measurements on loose sands are also included. In the relationship $R_s = R_{100}S^{-n}$ (R_s is resistivity at saturation S, and R_{100} the resistivity for complete saturation), n has been found to vary between 1·0 and 2·5. Variations in resistivity within the cores was noted, and successive runs on the same cores gave data differing by as much as 16% in some cases. Attempts to correlate the saturation exponent with porosity or permeability were unsuccessful. The exponent is apparently independent of the interfacial tension between the brine and the displacing medium.

There is evidence which suggests that the resistance of the core is not a unique function of the saturation, but depends on the way in which the saturation has been reached. The attainment of equilibrium may take several days. G. D. H.

1455. Multiple condensed phases in the methane–decane–tetralin–bitumen system. J. S. Billheimer, C. G. Yundt, B. H. Sage, and W. N. Lacey. *Petrol. Tech.*, Oct. 1949, **1** (10), *A.I.M.M.E. Tech. Paper No.* 2718, 265–70.—The results are presented for experiments made at 8000 p.s.i. and 220° F on a system in which the amount of methane was varied, but in which the less volatile component consisted of bitumen, decane, and tetralin in fixed proportions (0·0455 of bitumen, 0·0909 of decane, and 0·8636 of tetralin by weight). The measurements permitted the determination of the distribution of these components in the liquid phases.

The weight fraction of bitumen in the liquid phase was found to decrease rapidly as the weight fraction of methane in that same phase increased. A negligible amount of bitumen was indicated to be present in the gas phase. The data are presented graphically and in tabular form. Gas–liquid equilibrium " constants " of each of the components were found to vary markedly with the composition of the system.

G. D. H.

1456. Multiple condensed phases in the *n*-pentane–tetralin–bitumen system. J. S. Billheimer, B. H. Sage, and W. N. Lacey. *Petrol. Tech.*, Nov. 1949, **1** (11), *A.I.M.M.E. Tech. Paper No.* 2730, 283–90.—A restricted ternary system of *n*-pentane–tetralin–purified bitumen has been studied at 70°, 160°, and 220° F, and mainly at atmospheric pressure and 200 p.s.i. A few observations were made at 8000 p.s.i. The bitumen–tetralin weight ratio was 0·0526, and this solution was investigated in detail before studying the ternary system. On adding *n*-pentane to this solution bitumen was precipitated, and this separation occurred at lower weight fraction of *n*-pentane at the lower temperatures. Time influenced the amount of bitumen separated. With a weight of 0·271 *n*-pentane, all the separable bitumen appeared in 2 hr, but at 0·208 *n*-pentane only about a quarter of the separable bitumen appeared in 2 hr, and the rest during a week.

The bitumen-tetralin solutions show some colloidal characteristics below 160° F, when near compositions at which bitumen separated as a solid phase. An increase in pressure appears to increase the solubility of bitumen in tetralin–*n*-pentane solutions, and this effect was more pronounced above 160° F.

There are indications that at 70° and 160° F, when a second liquid phase appeared, the decrease in amount of bitumen separated as solid with increase in amount of pentane was due to solution of separated bitumen in the second liquid phase; the amount of bitumen in the original liquid phase decreased continuously as the amount of *n*-pentane increased.

The results are presented in tabular and graphical form, and in addition to a brief summary of earlier work, there are indications of the behaviour of crude-oil systems.

G. D. H.

1457. Multiple condensed phases in the decane–tetralin–bitumen system. J. S. Billheimer, H. H. Reamer, and B. H. Sage. *Petrol. Tech.*, Nov. 1949, **1** (11), *A.I.M.M.E. Tech. Paper No.* 2731, 279–82.—The behaviour of a series of decane–tetralin–bitumen systems has been investigated at atmospheric pressure and 8000 p.s.i. and temps of 70°, 160°, and 220° F. The weight-fractional compositions ranged as follows: decane 0·099–0·8; tetralin 0·190–0.856; bitumen 0·01–0·045. The ratio of bitumen to tetralin was constant. At 15 p.s.i. an increase in the amount of decane caused an increase in the relative quantity of bitumen separated, and there was no sign of the separation of a second liquid phase. At 800 p.s.i. the relative amount of solid phase rose with increasing weight fraction of decane until a second liquid phase appeared. Then a further increase in decane caused a decrease in the amount of solid at 70° and 160° F, although the total of bitumen in the second liquid and the solid phase rose continuously.

The experimental results are summarized in tabular and graphical form.

G. D. H.

1458. An electrical computer for solving phase equilibrium problems. M. Muskat and J. M. McDowell. *Petrol. Tech.*, Nov. 1949, **1** (11), *A.I.M.M.E. Tech. Paper No.* 2733, 291–8.—The theoretical basis of an electric computer for solving phase-equilibrium problems is described, and a simplified schematic circuit in addition to the twelve-circuit lay-out is shown. The computer can handle twelve-component problems, and

for six to twelve components the complete solution required 10–20 min, most of which time was spent in setting the voltages.

The solutions of a series of problems are presented, and comparisons are given for calculated and computer results. These comparisons show that the computer errors are small (generally less than 0·5%). The problems solved relate to flash vaporization and single-stage separation as a function of separation pressure. G. D. H.

Oilfield Development.

1459. World production of crude down 16 million barrels in 1949. Anon. *World Petrol.*, Jan. 1950, **21** (1), 26.—In 1949 world oil production was about 3,406,000,000 brl. The daily outputs of the leading countries in thousands of barrels were as follows: U.S.A. 5040, Mexico 164, Venezuela 1325, Colombia 82, Roumania 85, U.S.S.R. 690, Iran 556, Saudi Arabia 477, Kuwait 242, Egypt 45, Iraq 85, Indonesia 131·3, British Borneo 68.

Tables give the 1939, 1947, 1948, and 1949 average daily outputs by countries, and there are brief notes on the main features in the production of important areas. G. D. H.

1460. Foreign production gains, but world total down in 1949. D. M. Duff. *Oil Gas J.*, 26.1.50, **48** (38), 205.—Oil production outside the U.S.A. in 1949 averaged 4,268,600 b.d., compared with 3,840,200 b.d. in 1948. The figures for Canada, Venezuela, Colombia, Iran, Kuwait, Saudi Arabia, Indonesia, and Russia were, respectively, 59,000 b.d., 1,320,000 b.d., 82,300 b.d., 552,000 b.d., 245,000 b.d., 475,000 b.d., 112,000 b.d., and 690,000 b.d. The last figure is based on reported percentage increases.

A table gives the 1938, 1948, and 1949 outputs by countries. G. D. H.

1461. Concession contracts. D. M. Duff. *Oil Gas J.*, 9.2.50, **48** (40), 56.—A table has been prepared to show the salient features of contracts for oil exploitation in eleven countries: Canada, Colombia, Venezuela, Mexico, the Middle East, and Indonesia. It does not show the background of individual contracts, or refining or export obligations, exchange or tax requirements. These may be more important than rental or royalty payments.

Royalties range 3–20% or 8·5–55 cents/brl., periods of contract 30–75 years or the life of production. Rents vary in their nature. G. D. H.

1462. Exploratory and development drilling—where it occurred and the results. Anon. *Oil Gas J.*, 26.1.50, **48** (38), 319.—A series of tables give the following data for the various districts of the U.S.A.: the completions according to types by months in 1949; the wildcat completions similarly classified; the wildcat completions grouped according to countries; the development completions grouped according to fields. G. D. H.

1463. 37,414 wells, 138 million feet predicted for 1950 drilling. C. J. Deegan. *Oil Gas J.*, 26.1.50, **48** (38), 174.—7296 wildcats and 30,118 field wells are predicted for the U.S.A. during 1950. The 1949 actual figures were, respectively, 7294 and 31,744. 2822 wildcats and 11,175 field wells are expected to be drilled in Texas; Oklahoma is expected to have 925 wildcats and 2925 field wells, and Kansas 458 wildcats and 2585 field wells. Tables give the breakdown and footage by states, with an analysis of the overall forecasts for 1949. G. D. H.

1464. New all-time record set in footage drilled during 1949. Anon. *Oil Gas J.*, 26.1.50, **48** (38), 176.—39,038 wells totalling 138,002,964 ft were drilled in the U.S.A. in 1949. The footage was a record. 24,929 oil and gas wells were completed. Wildcats totalled 7294. Texas had 13,665 completions. The U.S.A. had 1382 service wells and 12,727 dry holes.

Tables give, by states, the 1949 numbers of oil, gas, service and dry wells, and the footage; the rotary and cable-tool wells; the numbers in different depth ranges; an analysis of the wildcat completions, and of development completions; the wildcat and development completions by months; the service and distillate completions by months; the yearly footage by states from 1942. G. D. H.

1465. U.S. oil men have found 60 billion barrels. Anon. *Petrol. Engr*, Nov. 1949, **21** (12), B-82.—60 billion U.S. brl oil have been produced in the U.S.A. since the Drake well. Since 1937, the number of producing wells in the U.S.A. has increased from 349,450 to 435,000 (1949). Daily average of production per well rose from 9·8 to 12·8 brl over the same period. Current proved reserves in the U.S.A. are approx 27 billion brl, an increase of 73% over the 1937 figure. C. A. F.

1466. 2% of fields account for 60% of oil found. C. J. Deegan. *Oil Gas J.*, 26.1.50, **48** (38), 184.—134 major fields in the U.S.A. are expected to produce 39,381,000,000 brl of oil, the U.S.A. total for all fields being predicted at 64,999,000,000 brl. Fifty-two of these fields are in Texas, thirty-two in California, and nineteen in Oklahoma.

Tables list the states with the numbers of major fields and their expected aggregate ultimates; the major fields with their year of discovery, estimated ultimate production, cumulative production, remaining reserves, 1948 and 1949 production, age, and type of producing formation. G. D. H.

1467. Annual, cumulative production, and remaining reserves by fields. Anon. *Oil Gas J.*, 26.1.50, **48** (38), 246.—The larger U.S.A. fields are grouped according to districts, with the 1949 production, cumulative production to the end of 1949, estimated reserves at the end of 1949, and the number of wells. G. D. H.

1468. Crude production off 468,000 b.d. from 1948 high. J. C. Casper. *Oil Gas J.*, 26.1.50, **48** (38), 188.—In 1949 U.S.A. crude-oil production averaged 5,043,000 b.d., a decrease of 468,000 b.d. compared with 1948. Texas produced a total of 746,244,000 brl in 1949, a decrease of 157,074,000 brl compared with 1948. At the beginning of 1950 the U.S.A. had 420,695 producing wells, and the overall daily average output per well was 12 b.d. The U.S.A. cumulative production to the end of 1949 was 39,019,219,000 brl.

Tables give the yearly production in the U.S.A. by states from 1943 onwards, together with the cumulative to date, and the number of wells at the beginning of 1950. G. D. H.

1469. Oil and gas in Arbuckle and Ellenburger formations, Mid-Continent region. J. G. Bartram, W. C. Imbt, and E. F. Shea. *Bull. Amer. Ass. Petrol. Geol.*, 1950, **34**, 682–700.—The varying conditions under which commercial oil and gas pools occur in the Arbuckle–Ellenburger formation throughout the Mid-Continent region of the U.S.A. are shown in cross-sections and maps.

Certain general features seem to be common to all areas, both producing and barren, while other features differ widely between producing areas.

The Arbuckle formation of Cambro–Ordovician age has been the most important producer of oil in Central Kansas for many years, and the Ellenburger formation of approximately equivalent age is now actively developed in West Texas and southeast New Mexico.

It is interesting that oil and gas should have accumulated in these two widely separated areas, while in the intervening region, few pools of importance have been developed. It is felt that a continued and systematic programme of exploration and development may lead to a better understanding of the fundamental factors governing oil accumulation in these strata, and result in the discovery of additional oil and gas pools. E. N. T.

1470. Oil and gas in Eastern Kansas. J. M. Jewett. *Bull. Geol. Surv. Kansas, No.* 77, July 1949.—Each of the forty-three counties is treated separately, brief descriptions of the surface and subsurface geology are given, and oil and gas development is discussed. Tables show annual oil production by counties and yearly field production from 1944 to 1948.

Eastern Kansas comprises the forty-three counties lying wholly east of the 6th principal meridian. Oil and gas were discovered in the state in 1860, and peak production was reached in 1918.

Exposed rocks are Cretaceous, Permian, Pennsylvanian, and Mississippian, which in

general dip gently westwards. The subsurface geology is complex, due to the presence of several structural elements, of which the Nemaha anticline is the most prominent.

Four north–south sections are included. C. A. F.

1471. Oil and gas developments in Kansas during 1948. W. A. Ver Wiebe, J. M. Jewett, and E. K. Nixon. *Bull. Geol. Surv. Kansas No.* 78, Sept. 1949.—Kansas oil production in 1948 was 108,080,654 brl, 4% more than in 1947. Natural-gas production was 240 U.S. billion cu. ft., of which the Hugoton field produced 186 billion cu. ft.

3285 wells were drilled in 1948, of which 1656 found oil, 351 gas, and 1207 were dry. 248 of the dry holes were wildcats.

The Trapp pool was the largest producer with 10·4 million brl. C. A. F.

1472. 20,000 ft goal reached; also new producing depth record set. P. De Armond. *Oil Gas J.*, 26.1.50, **48** (38), 182.—The world's deepest well is 20,521 ft, and lies in Sublette County, Wyoming; the deepest producer is at 15,530 ft at Wasco in Kern County, California.

The drilling and producing depth records are listed by states, with the location of the wells, their depths, deepest formations, year of completion, and results.

G. D. H.

1473. Canada takes rank among world's great producers. J. L. Irwin. *World Petrol.*, Jan. 1950, **21** (1), 24.—In the first ten months of 1949 Alberta produced 16,732,421 brl of crude and natural gasoline, 5,758,583 brl more than in the whole of 1948. Known oil reserves in Alberta are estimated at 1,500,000,000 brl, and the gas reserve is put at 6,000,000,000 M.c.f. Leduc has a gas-conservation plant.

In the first half of 1949 fees, rentals, royalties, and lease purchases yielded $15,036,956 to the Alberta Government. Seventy-two seismic parties and twenty-nine other geophysical parties were operating in Alberta late in 1949. Saskatchewan had twenty-four geophysical parties and Manitoba two.

Imperial Oil Company spent $23,000,000 searching for new fields before it discovered Leduc in 1947.

Western Canada has 67,000 b.d. of refining capacity, and this is to be expanded to 90,000 b.d.

A drilling programme is being undertaken on Graham Island. Leduc may have an extension to the west in two new wells. An old well 20 miles south of Vermilion has tested 68,000 M.c.f./day. G. D. H.

1474. Dutch output exceeds 4,000,000 barrels in 1949. Anon. *Petrol. Engr*, Jan. 1950, **22** (1). B-70.—Production from the Schoonebeek field in 1949 was over 4 million brl, compared with 40,000 brl/year at the end of the German occupation. C. A. F.

1475. The Delhi area fields, Louisiana. F. G. Prutzman. *Petrol. Engr*, Feb. 1950, **22** (2), B-7.—The Delhi area group comprises the Delhi–West Delhi, South Delhi, Big Creek, and South Big Creek fields, which form a belt of production approx 17 miles by 3 miles. The discovery well, sited on a seismic feature, was completed in 1944.

The structure is a stratigraphical trap along the south flank of the Monroe Platform caused by truncation of Lower Cretaceous sands by younger beds.

Main production is from the Lower Cretaceous Holt–Bryant Zone, and there are smaller reservoirs in stray Tuscaloosa sands in the Upper Cretaceous. Cumulative production of the group is approx 35 million brl, of which the Holt–Bryant Zone has yielded 25 million brl.

Drilling and production practice is described. C. A. F.

1476. Drilling in Germany. Anon. *Petrol. Engr*, Nov. 1949, **21** (12), B-85.—Thirty-three wells were drilled in the Steimbke–Rodewald field during the first six months of 1949. Of these, twenty-six were oil producers, one gas, and six were dry. The field was discovered in 1936, and averages 1000 b.d. of low-gravity oil from 660 to 2100 ft in sandy shale and limestone.

Two producers and one dry hole have been drilled in the Thören field, and three dry holes in the Hambühren field. C. A. F.

1477. Oil in the Netherlands and Elmsland (Germany). A. J. Mulder. *J. Inst. Petrol.*, 1950, **36**, 123.—A description is given of oil exploration in the Netherlands and the German Elmsland area from the beginning up to date, including geophysical investigations, core drilling, and exploration wells.

Geological results so far achieved are indicated, and the development of Schoonebeek and the Western Germany oilfields, including the newly discovered German field of Rühler Twist, is dealt with. A. R. W. B.

Transport and Storage.

1478. Net cost of oil transport by pipe line. H. Grünewald. *Erdöl u. Kohle*, 1950, **3**, 179–83.—Net cost of pipelines is considered, with especial reference to the three main factors influencing it, pipe dia, product visc, and line capacity. Calculations were made on assumption of a max pump pressure of 60 atm, line utilization of 660 hr/year (100%), product d of 0·9, line length (level) of 1000 km. For visc up to 5° E rotary pumps are best, reciprocating pumps can be used for all visc up to 10° E, for visc $>10°$ E heating of product is desirable. Curves are given showing net cost of transport (per ton-km at 1943/4 prices) for products of 1, 3, 5, 7, 10° E visc using diesel-driven reciprocating pumps, and for 1, 3, 5° E visc using electric-driven rotary pumps for lines of dia 200, 300, 400, and 500 mm. The effect of utilization factor is typified by curves for a 3° E product in a 400-mm line, using rotary pumps, at utilization factors of 40, 60, 80%. All curves cover range up to line capacity of 9 million tons/year. At greater line capacities effect of a low utilization factor is less. V. B.

1479. Oil pipeline construction. N. J. Harris. *Mech. World*, 12.5.50, **127** (3304), 526.—The paper consists of some notes on the laying of the pipeline to Bandar Mashur, for which some of the most recently developed methods were used. To hasten the project a line of considerably larger diameter than the normal 12 in pipe was installed, and by selecting a high-ground terminal at the field the oil could be induced to flow by means of gravity alone. This eliminated time and money spent on providing pumping equipment, and made possible the use of comparatively thin-walled pipe, since it would not be subjected to as much strain as if used to convey oil under pressure from pumps. The pipe was made from rolled plate and electrically welded longitudinally. Use of thin-walled pipe made it undesirable to run pipe across desert's surface, because of tendency to buckle. A 40-mile trench was therefore dug. Pipe was cleaned, primed, and coated against soil corrosion, and further protected against corrosion by means of an electric current arranged to flow into the pipe in opposite direction to naturally flowing currents responsible for much corrosive action. The total quantity of crude oil contained in the new line is 3·5 million gal, approximately the capacity of a 12,000-ton-dead-weight tanker, and when operating at full capacity the crude oil takes 14 hr to complete its 45-mile journey. A. S.

1480. River crossings on the transcontinental system. F. H. Chilson. *Oil Gas J.*, 4.5.50, **48** (52), 105.—The transcontinental pipeline river crossings between source at Rio Grande, Texas, and terminus at Manhattan Island, New York, are described.

Of the rivers crossed, four are by means of aerial suspension bridges, nine by multiple lines, and twenty-seven with single lines.

In general, suspension systems were used where water had excessive depth, banks were steep and high; whereas the multiple crossing was employed for exceptionally long crossings and where river had swift currents. Single underwater crossing was used where river was narrow and current slow, and location remote from market area. The Hudson River crossing demands, because of bottom of penetrable fine organic silt to a depth of 100 ft, a unique method, using air and water jets, the pipe being pulled into place and laid down 25 ft below river bottom. It is planned to weld this section into a continuous line on a long series of barges using an automatic submerged-arc process. G. A. C.

1481. New, safe, practical storage and transportation method for light hydrocarbons. C. V. Spangler, W. W. Bodle, and W. T. Granquist. *Oil Gas J.*, 20.4.50, **48** (50), 170.—The results of pilot-plant operation on methane are given, and extension of process for handling propane, butane, etc., discussed.

The natural gas is stored in above-ground container filled with fuller's earth, where the gas is not free to flow in case of tank failure and release of gas from granular adsorbent is relatively slow, even if gas is actually burning at surface.

In the pilot-plant adsorption was effected by trickling liquid methane down through a bed of the granular adsorbent.

Data were obtained on adsorbent beds containing 5 lb and 63 lb of adsorbent, having capacities of 50 and 630 standard cu. ft. respectively.

Variables studied included effect of temperature and pressure on adsorption, adsorption characteristics, and comparative ignition characteristics of both liquid methane and "soaked" methanite.

It is thought that the system could be incorporated in the design of railcars, barges, and tankers, the adsorbent in the latter two cases being arranged in steel boxes.

G. A. C.

1482. Domed aluminium roof is unique structure. Anon. *Oil Forum*, Apr. 1950, **4** (4), 144.—The weight of a domed aluminium roof developed by Aluminium Construction Ltd. is considerably less than that of a standard steel roof. Transportation and erection costs are therefore reduced, and maintenance is negligible in all but the most corrosive atmospheres and conditions. The plan dia of the roof is 82 ft 6 in, and its weight is 4½ tons, as compared with 32½ tons, which is the weight of an ordinary steel roof constructed to A.P.I. standards. All the ribs are made great circles of radius 100 ft so that they are interchangeable. The framework is comprised of tubular ribs, square in section and the covering is thin aluminium sheeting. Economic considerations suggest that the cost of this roof compares very well with that of a standard steel roof for a tank of equal dia, and that for larger tanks the aluminium roof would be considerably cheaper. The chief attraction of this type of roof, however, is in the fact that it is more resistant to corrosion. A. S.

1483. Patent. C. E. Reedy, assr. to American Car and Foundry Co., U.S.P. 2,496,677, 7.2.50. A tank-car nozzle for high-pressure tanks. C. F. S.

Refinery Operations.

Refineries and Auxiliary Refinery Plant.

1484. Modern trends in industrial water treatment. R. C. Ulmer and E. A. Lowenthal. *Oil Gas J.*, 13.4.50, **48** (49), 92.—Problems in treatment of water for boilers, caused by scale, sludge corrosion, biological deposits, and carryover are reviewed.

Use of water should be defined; and safe operating concentrations determined to decide whether the raw water requires external or internal treatment.

Permissible limit for total hardness should be governed by amount of suspended matter likely to form rather than scale.

Excessive alkalinity contributes to carryover, and total dissolved solids are a measure of this tendency.

Silica is of concern, but more so in control of turbine-blade deposits than deposits in boilers.

A table shows comparison of operating results of various methods of water treatment.

G. A. C.

1485. Heat emission by free convection from spherical surfaces. D. I. Boyarintsev. *Izvest. Akad. Nauk S.S.S.R., Otdel. Tekh. Nauk*, 1950, 249–52.—Tests were made with spheres of dia 3–6 cm (in water), 6 cm (in CO_2) and 3–250 cm (in air). Spheres were coated with Al foil and a radiation correction made. Heating was by internal electric heaters. Examination of the possible errors showed these to be (if cumulative) 6% in the determination of the heat-emission coeff (a) and 4% and 7% in determination of Gr and Nu respectively. a varies inversely with sphere dia up to a dia of

56 cm, but for dia >56 cm a becomes independent of the dia at ordinary temp, this is a variation from the critical value of 70 cm for the dia previously reported by Nusselt. a increases slowly with rise of temp difference between sphere and surrounding medium. Within the experimental range investigated two relationships were observed, when $4{\cdot}4<\log(GrPr)<9{\cdot}1$ $Nu = 0{\cdot}56(GrPr)^{\frac{1}{4}}$ and when $8{\cdot}0<\log(GrPr)<10{\cdot}0$ $Nu = 0{\cdot}13(GrPr)^{\frac{1}{3}}$. V. B.

1486. Designing the flash tank. T. W. Reynolds. *Heating & Ventilating*, Apr. 1950, **47** (4), 74.—A flash tank permits condensate at high pressure to flash into steam for use in a low-pressure steam-heating system or in heating a hot-water supply. The paper supplies information connected with the design of such tanks and correct tank sizes. A table gives flash-tank dimensions for various steam capacities. A. S.

1487. New device perfected for lighting pilot light on elevated flare stacks. O. L. Clevenaer and W. A. McElhannon. *Oil Gas J.*, 30.4.50, **48** (47), 91.—The equipment consists of a 1-in continuous pilot gas-line from ground to top of stack with a 10-ft length of 2 in-line adjacent at top of stack. Latter line is perforated at lower end to admit air, and connected to a needle valve and gas supply. An electrical heating element incorporated is energized to reach 1800° F in 20 sec, then small amount of gas is introduced and ignited by element, travels to top of 2-in line and ignites gas from the continuous pilot. G. A. C.

1488. Wall flame rotary oilburners. Part I. Principles of operation and types of burners. P. G. Coale. *Fuel Oil & Oil Heat*, Apr. 1950, **9** (4), 82.—A brief review of the history of the wall-flame rotary burner is given. The advantages of the wall-flame burner and those of the gun burner are considered. The former type performs more satisfactorily in the short-pass boiler, giving lower fuel consumption. The flame ring of the wall-flame rotary burner rapidly reaches a combustion supporting temp which reduces the waste of fuel in long heating-up periods. The stages of the oil-burning process are listed, and the theory of the fuel-oil combustion is briefly discussed.

Figures illustrate the three most popular types of wall-flame burners of to-day. The three burners employ the same basic principles, the main difference being that one has discharge-air regulation and gravity fuel feed to the oil-distributing cup, while the other two types employ intake-air regulation and a mechanical fuel lift to the oil-distributing mechanism.

A diagram illustrates a typical burner installation, and its method of operation is discussed. D. K.

1489. Patents. K. M. Watson, assr. to Sinclair Refining Co. U.S.P. 2,497,106, 14.2.50. Apparatus especially adapted to the pyrolytic conversion of hydrocarbons.

J. A. Patterson, assr. to Standard Oil Development Co., U.S.P. 2,497,136, 14.2.50. An improved vapour–liquid contacting unit.

S. J. H. Breukel, assr. to Shell Development Company, U.S.P. 2,497,392, 14.2.50. A tube settler for separating immiscible liquids of different specific gravities.

N. P. Peet, assr. to Standard Oil Development Co., U.S.P. 2,496,356, 7.2.50. A catalytic reactor.

R. Eichenberg, assr. to McEvoy Co., U.S.P. 2.496,451, 7.2.50. Refinery valve.

A. V. B. Candler. U.S.P. 2,496,518, 7.2.50. An automatic shut-off valve for a pipeline between an oil-tank and a suction pump. C. F. S.

Distillation.

1490. Algebraic calculation of distillation columns. B. J. Alder and D. N. Hanson. *Chem. Engng Prog.*, 1950, **46** (1), 48–54.—The distillation equations of Underwood for multicomponent systems are re-arranged to allow the use of determinants, resulting in a rapid solution for multicomponent systems which may, by successive approximation, be made as exact as desired. The method is applicable to any multicomponent system where the initial assumptions of constant relative volatility and constant flows can be made. J. G. H.

1491. Multicomponent distillation. 11. Application of algebraic equations to doublet separation. P. G. Murdoch. *Chem. Engng Prog.*, 1950, **46** (1), 36–43.—Doublet separations are those in which the key components are adjacent and are the only components appearing in appreciable proportions in both products of a distilling column. For doublet separations general equations derived in an earlier paper (*Chem. Engng Prog.*, **44**, 855) reduce to relatively simple forms which are presented with both accurate and approximate methods for their solution. J. G. H.

1492. Plate efficiencies in separation of C_4 hydrocarbons by extractive distillation with furfural. E. W. Grohse, R. F. McCartney, H. J. Hauer, J. A. Gerster, and A. P. Colburn. *Chem. Engng Prog.*, 1949, **45** (12), 725–38.—Plate efficiencies were determined in a 13-in int dia ten-tray, pressure-distillation column used to separate *iso*butane from 1-butene in the presence of furfural and furfural–water solutions as the separating agents in an extractive distillation operation. Trays and operating variables were arranged to simulate conditions occurring in an actual *iso*butane tower. Over a wide range of operating variables studied, Murphree plate efficiencies varied between 47 and 61%, with corresponding local efficiencies ranging between 39 and 51%. Results compared with correlations reported in the literature indicate a special need for liquid film data. J. G. H.

1493. Plate efficiencies related to separate vapour and liquid resistances. J. A. Gerster, A. P. Colburn, W. E. Bonnet, and T. W. Carmody. *Chem. Engng Prog.*, 1949, **45** (12), 716–24.—Single-film plate efficiencies were determined for a 13-in dia plate of identical design with that used in the study of plate efficiencies in the separation of C_4 hydrocarbons by extractive distillation with furfural. Pure gas film efficiencies were obtained by measuring the degree of humidification of air passing upward through water flowing across the plate at the wet-bulb temp. Pure liquid-film efficiencies were obtained by measuring the amount of oxygen capable of being desorbed from the water by the air. The effect of varying gas and liquid rates upon each film resistance is shown. Convenient methods for combination of single-film resistances in plate columns to predict overall two-film resistances in other systems are compared and amplified. J. G. H.

1494. Correlation of plate efficiencies in fractionating columns. J. C. Williams, E. K. Stigger, and J. H. Nichols. *Chem. Engng Prog.*, 1950, **46** (1), 7–16.—Data, observations, and conclusions are presented on the overall efficiencies of a bubble-cap rectification column when operated with eight different binary distillation systems representing a wide range, both in respect to chemical structure and physical properties. All acceptable data were correlated on the O'Connell system, where overall efficiency is a graphical function of the relative-volatility–viscosity product. Over the range tested, the accuracy of the O'Connell correlation appears to be satisfactory for column design if normal reflux ratios are used, and if the operation is not primarily of stripping character. J. G. H.

1495. Efficiency of packed fractionating columns—effect of vacuum operation. R. T. Struck and C. R. Kinney. *Industr. Engng Chem.*, 1950, **42** (1), 77–82.—The effect of vacuum operation on packed fractionating column eff was investigated in a 0·75-in column packed with : Raschig rings, Fenske stainless-steel helices, Cannon protruded packing, and McMahon wire-gauze saddles. Eff was found to vary little with pressure. Vapour–liq equilibrium data are reported. Total hold-up of the column was found to vary linearly with pressure drop, being higher at lower head pressures. Pressure drop was found to give straight-line log–log graphs with distillation rate. Max eff from all packing occurred at 50–100 mm. Experiments showed eff of packings to increase in the order stated above. Effect of pressure on eff was apparently independent of the packing used. R. G. T.

1496. Vapour–liquid equilibria in binary systems (water–2-methyl-3-butyn-2-ol and water–3-hydroxy-3-methyl-2-butanone). A. Z. Conner, P. J. Elving, J. Benischeck, P. E. Tobias, and S. Steingiser. *Industr. Engng Chem.*, 1950, **42** (1), 106–10.—Vapour–liquid equilibrium data at atm pressure are shown for the above two systems.

Isopiestic activity coeffs for the components in each system are thus calc and Van Laar equations derived which agree with experimental data. B.p., composition, vapour–liq equilibrium, and activity coeff composition in graphs are shown for each. Azeotropes and refractive index–composition relations are described for each system. Vapour pressure–temp correlations were determined for the two organic components. R. G. T.

1497. Thermodynamic correlation of vapour–liquid equilibria—determination of activity coefficients from relative volatility. R. Gilmont, E. A. Weinman, F. Kramer, E. Miller, F. Hashmall, and D. F. Othmer. *Industr. Engng Chem.*, 1950, **42** (1), 120–6.—A new thermodynamic method of correlating vapour–liq equilibria is described. Correlation can be made by a single equation without b.p. data by determining activity coeffs from relative volatility data. The latter are expressed as a power series in terms of a composition variable. Evaluation of the series is made graphically from the experimental data. Various transformations are derived: (1) to convert relative volatility coeffs to activity coeffs; (2) to convert activity coeffs of the first component to those of the second component and finally the inverse of coeff (1) is derived. A new criterion for thermodynamic consistency of vapour–liq equilibria data has been obtained from the relation between ideal relative volatility and relative volatility coeffs. This relation also shows any association or dissociation. R. G. T.

1498. Volumetric and phase behaviour of propane–benzene system. J. W. Glanville, B. H. Sage, and W. N. Lacey. *Industr. Engng Chem.*, 1950, **42** (3), 508–13.—Determination is made of sp. vol. of propane–benzene mixtures at pressures from 100 to 10,000 p.s.i.a. and seven temps between 40° and 460° F. Dew-point gas was analysed at five temps between 10° and 460° F for pressures between the v.p. of benzene and crit pressure of the system. Results are tabulated and some are represented graphically. R. G. T.

1499. Diffusion coefficients in multicomponent gas mixtures. D. F. Fairbanks and C. R. Wilke. *Industr. Engng Chem.*, 1950, **42** (3), 471–5.—Diffusion of vapours into multicomponent gases has been studied. Liquids are vaporized in a long tube under such conditions that the theory of diffusion in the semi-infinite column is applicable. The relation

$$D_A = \frac{1 - \gamma_A}{\frac{\gamma_B}{D_{AB}} + \frac{\gamma_C}{D_{AC}} + \frac{\gamma_D}{D_{AD}}}$$

is verified [D_A is effective diffusion coeff of A with respect to the total mixture; D_{AB}, D_{AC}, D_{AD}, etc., are binary diffusion coeffs. γ_A, γ_B, γ_C, are mol fractions of components. R. G. T.

1500. Processing methods in a gasoline plant to obtain 85% propane recovery. C. P. Stanley. *Oil Gas J.*, 20.4.50, **48** (50), 157.—Field gas from four different pools is processed to recover 85% of the propane and 99% of butanes and heavier hydrocarbons.

As water supply was very hard and not readily available, where possible, all cooling is by air-finned coolers. There being no steam facilities, heating is by direct-fired oil heaters.

The rich-oil demethanizer operates at 250 p.s.i.g. All the methane and most of the ethane is removed, and conventional depropanizer and debutanizer deal with the butane and propane. G. A. C.

1501. Patent. G. Purcell and D. C. Hausch, assrs. to Shell Development Co., U.S.P. 2,496,253, 31.1.50. The production of xylenes by fractional distillation of a mixture consisting of xylenes, dimethyl*cyclo*hexanes, and paraffin hydrocarbons. C. F. S.

Absorption and Adsorption.

1502. Heat of wetting of activated bauxite and attapulgus clay. S. G. Miller, H. Heinemann, and W. S. W. McCarter. *Industr. Engng Chem.*, 1950, **42** (1), 151–3.—Deter-

mination of heat of wetting of various adsorbents is described, and heat of wetting, data for several organic liquids and water are supplied for activated Al_2O_3 and attapulgus clay. Relation between heat of wetting and activation temp and residual water content is studied for Al_2O_3, heats of wetting depend on surface area. With clay, surface area is mainly constant, and the residual water content has more effect on the heat of wetting. Wetting data compared with those of silica gel and charcoal suggest that wetted area varies according to shape and size of the wetting mol. Dipole moment of the liquid is not important. Liquids of similar molecular structure show similar heats of wetting, especially with Al_2O_3. R. G. T.

1503. Patents. E. V. Fasce, assr. to Standard Oil Development Co. U.S.P. 2,497,159, 14.2.50. Separation of olefins by contacting with a solution of cuprous salt in an organic nitrogen base to form an extract solution and a non-absorbed raffinate fraction, and separating the solution from the raffinate.

R. N. Shiras, assr. to Shell Development Co. U.S.P. 2,497,421, 14.2.50. An absorption process of absorbing volatile hydrocarbons from mixed gases. C. F. S.

Solvent Extraction and Dewaxing.

1504. Solid–liquid extraction calculations. J. A. Grosberg. *Industr. Engng Chem.*, 1950, **42** (1), 159–62.—A method is shown for solution of standard equations for extracting soluble material from solids (in the case of constant underflow) which obviates the cumbersome trial and error methods. Variation of underflow vol with solute concn is explained and equations derived accordingly. Previous work is cited as verification of the theory which has enabled modification of the standard equations for variable underflow. Non-equilibrium conditions are also discussed, and analytical methods described which are little more complicated than those for equilibrium conditions. R. G. T.

1505. Extractable waxes from American lignites (laboratory investigation). W. H. Ode and W. A. Selvig. *Industr. Engng Chem.*, 1950, **42** (1), 131–5.—Results are shown of a U.S.B.M. survey of the solvent extraction yields of U.S. lignites. Highest yields, shown with Arkansas and Californian lignites were similar to those obtained in commercial extraction of montan wax from German brown coals. Extract yields from sub-bituminous coals were appreciably lower. For same lignite higher yields were obtained with mixture of benzene and alcohol than with benzene, but the benzene extracts more closely resemble commercial wax. U.S. lignites give waxes with greater resin content than the German coal studied. The benzene alcohol extracts gave higher asphalt content than benzene extracts. It is suggested that the resins and asphalts could be removed by suitable solvents. R. G. T.

1506. Toluene extraction from petroleum with water. G. B. Arnold and C. A. Coghlan. *Industr. Engng Chem.*, 1950, **42**, 177–82.—Recovery of toluene from toluene concentrate from petroleum stocks by liq–liq extraction with water based on equilibrium data indicates that recovery is feasible if carried out at about 300° C. Charge oil with less than 50% toluene would not be very useful, and thus stocks are used which have been dehydrogenated prior to extraction. Solvent dosage and number of stages required with toluene content >50% require a tower of feasible dimensions, but pressures are above those usually encountered. R. G. T.

1507. Patent. J. A. Davies, assr. to the Texas Company. U.S.P. 2,497,588, 14.2.50. Method of refining oil with a selective solvent. C. F. S.

Cracking.

1508. Moving bed catalytic cracking correlations; product distribution and process variables. J. W. Schall, J. C. Dart, and C. J. Kirkbride. *Chem. Engng Prog.*, 1949, **45** (12), 746–54.—Results are presented of a pilot-plant investigation to determine the effect of process variables of space rate, catalyst-to-oil ratio, and temp on product distribution and quality in moving-bed cat cracking. Data were obtained from

once-through cracking of an East Texas heavy gas oil over plant-aged silica–alumina–bead catalyst. The correlations derived indicate that catalyst-to-oil ratio and space ratio are interchangeable variables which can be used in an infinite number of combinations in order to obtain a particular product distribution at a given temp.

J. G. H.

1509. Ageing of cracking catalysts (loss of selectivity). G. A. Mills. *Industr Engng Chem.*, 1950, **42** (1), 182–7.—Loss of selectivity of petroleum cracking cats was investigated in a study of effect of conditions to which cats are exposed. Corroboration of results was made by analysis of the ash for oils with harmful effects: the presence of heavy metals—iron, nickel, vanadium, and copper in active form in the cat is thus shown to be primarily effective even in minute amounts. These metals from the pet stock may be carried by entrainment to the cat. Clay and synthetic cats are similarly affected. Loss of selectivity is usually due to reaction of S compounds with iron which is thus made catalytically active. Steam retards the reaction and calcination of the cat renders the iron less active. Gases to which cats may be subjected are classified according to their effect on SiO_2–Al_2O_3 cats at temps up to 1400° F.

R. G. T.

1510. Gas-phase hydrogenation of petroleum and cracking. G. Free. *Erdöl u. Kohle*, 1950, **3**, 162–7.—Cracking leads to H_2-enrichment of some of the products and consequent H_2-impoverishment of others. Cracking processes (thermal and cat) are briefly reviewed and are compared to cat gas-phase hydrogenation; cat-cracked gasoline has the higher O.N., but yield is less. A scheme is suggested for combining cat cracking with cat hydrogenation of the H_2-poor middle-oil fraction obtained by cat cracking. Two variations are schematically described, one involving recycling (after hydrogenation) of cracked gas oil through the cracker, resulting in a yield (on original gas-oil feed) of 70 wt-% of 78–80 O.N. (190° C., E.P.) gasoline + 21% of liquefied pet gas (which can also be used as motor fuel) and the other in which the gasoline obtained from cat cracking of gas-oil feed is blended with that obtained by cat hydrogenation of the cracked gas oil, giving an overall yield of 79 wt-% of 73 O.N. (190° C, E.P.) gasoline which can be increased to a total motor-fuel yield of 95% by incorporation of liquefied pet gas. Importance of such processes, yielding max amounts of motor fuel, to countries relying on imported pet supplies is stressed. V. B.

1511. Platforming—solution for reforming straightrun crude. D. V. Haensel. *Oil Gas J.*, 30.4.50, **48** (47), 82.—Platforming of a straight-run gasoline is a relatively low-temperature operation, and consists in dehydrogenation of naphthene hydrocarbons to corresponding aromatic hydrocarbons; a reaction wherein a high-molecular-weight hydrocarbon is decomposed into lower-molecular-weight compounds and thirdly, isomerization whereby five-membered ring naphthenes are converted to six membered ring naphthenes prior to change to aromatics.

There are four major operating variables in the process, namely temperature, space velocity, pressure, and hydrogen recycle rate, and tables show the effect of these variables, together with one showing properties of the platformate.

The economics of the process is also briefly discussed. G. A. C.

1512. Platforming of natural gasoline. E. K. Sutherland and D. D. Hanson. *Oil Gas J.*, 20.4.50, **48** (50), 177.—A debutanized natural gasoline with an end-point of 400–410° F when platformed is upgraded, the octane rating being improved with a minimum increase in the amount boiling below 212° F. Platforming is a non-regenerative catalytic reforming process by which the gasoline is reformed at high liquid volumetric recovery in the presence of a platinum catalyst in a hydrogen atmosphere to obtain high-octane products. Four principal reactions are dehydrogenation of naphthenes to aromatics, hydro-cracking of high-mol.-wt. paraffins to lower-mol. wt. paraffins, isomerization of paraffins and naphthenes, and desulphurization of sulphur compounds forming H_2S. All the reactions lead to octane-number improvement.

A typical platforming unit consists of a feed-preparation section, reaction and stabilization actions.

One table shows typical results from platforming, and others give effect of by-

passing the light gasoline on yield–octane relationship, operating costs, and practical road-ratings of two platformates. G. A. C.

1513. Old Dutch Refining Co. finds platforming ideally suited to its needs. G. Weber. *Oil Gas J.*, 6.5.50, **48** (48), 62.—The 1500-brl unit of the Old Dutch Refining Co., at Muskegon, Mich., is described. Prefractionated charge stock is platformed, during which three reactions take place: naphthenes are dehydrogenated to aromatics, heavier paraffins cracked, and lighter paraffins isomerized. The three reactors containing identical catalyst operate at 700–725 p.s.i. from 920° F downward; liquid product from separator is stabilized to specification and stored without treatment.

Tables show performance data on the unit whilst operating at 1000 and 1500 b.d., and overall refining gasoline yield.

Costs, assuming new equipment, amount to $465 per brl daily on a unit processing 1500 b.d. and on a 10,000-b.d. throughput would be $250 brl daily. G. A. C.

1514. New catalytic reformer produces 82-octane fuel from Michigan naphtha. Anon. *World Petrol.*, 1950, **21** (4), 30–3.—New cat-reforming process (platforming) is described. Fixed-bed cat of Pt-bearing material is used in a series of three reactors. Naphtha (180–390° F) passes through the reactors at 700 p.s.i. and 875–925° F. Gas is recycled and liq products stabilized. Design capacity is about 1500 b.s.d., and costs of processing are 20–35 cents/brl exclusive of amortization. Initial plant cost was $700,000. Cat life is 6–12 months, after which it is discarded and Pt recovered. Main reactions are: (1) dehydrogenation of naphthenes (endothermic); (2) hydro-cracking (exothermic), and (3) isomerization of 5- to 6-membered naphthenes, which then undergo reaction (1). Dehydrocyclization of paraffins and S removal (82–97%, mainly as H_2S) are also of importance. There is little production of CH_4, even at high pressure, and reaction (1) quenches (2) as temp is increased, thereby aiding temp control. Platformate does not require rerunning. At plant described naphtha O.N. was increased from 50 to 82 (cf. increase to 74 by thermal cracking) and yield of 10 R.V.P. gasoline (O.N. 94 after leading) was 97%. E. B.

Hydrogenation.

1515. Hydrogenation of bituminous coal in experimental flow plant. (Process variable study.) M. A. Elliot, H. J. Kandiner, R. H. Kallenberger, R. W. Hiteshue, and H. H. Storch. *Industr. Engng Chem.*, 1950, **42** (1), 83–91.—Authors describe experimental flow plant for hydrogenation of coal–oil pastes at elevated temps and high pressure. Preparation of heavy fuel oil by hydrogenation of two particular coals is reported. Correlation of the process variables is plotted. Temps from 420° to 480° C, and contact times from 1 to 80 min, and coal concns in the feed of 20–50% by wt were used. Stannous sulphide–iodoform and molybdenum trioxide cats were tested. Other variables evaluated were residual O_2, asphalt, S, and non-distillate soluble-oil content; viscosity; soluble-oil yield, H_2 absorbed and hydrocarbon gas formed. These are correlated with temp, contact time, paste-composition catalyst, and coal used.

Effect of product viscosity on oil yield, H_2 absorbed, and gas formed was investigated. High temp, long contact times, and more active cats reduce product viscosity and b.p. and increase H_2 and light hydrocarbon formed, and removal of O_2, S, and asphalts from the feed. Soluble-oil yield shows a complex relation, optimum yields arising from low contact times. R. G. T.

1516. Coal hydrogenation catalysts—batch autoclave tests. S. Weller, M. G. Pelipetz, S. Friedman, and H. H. Storch. *Industr. Engng Chem.*, 1950, **42** (2), 330–4.—Catalyst tests have been carried out for the hydrogenation of three coals. The effect of various compounds on the process is recorded. Ammonium chloride had negative action or none at all. Tin showed moderate cat activity by itself, but with halogen acid constitutes the best-known cat for coal hydrogenation (with the exception of germanium plus halogen acid). Other promoters for tin, as efficient as halogen acid, were ammonium chloride, carbon tetrachloride, and the chloroacetic acids. Salt is inert and chlorine shows a deleterious effect. Molybdena, nickel on kieselguhr, copper chromite and iron compounds were found to be useless as cats. Zinc with ammonium

chloride is appreciably active as cat. The physical distribution of tin was shown to be important but for good distribution the chemical form had little effect. Stannous sulphide, metastannic acid, and tin tetraphenyl being as effective as tin. Increase of metal above 0·5% of the coal mass has little effect. Increase in ammonium chloride decreased the asphalt content of the products. Iron cats, ferrous sulphate, pyrite, or " red mud " were reasonable cats (but not as active as tin) at pressures of the order of 3700 p.s.i. R. G. T.

1517. Coal hydrogenation catalysts—mechanism of coal hydrogenation. S. Weller, E. L. Clark, and M. G. Pelipetz. *Industr. Engng Chem.*, 1950, **42** (2), 334–6.—Study of the influence of catalysts on hydrogenation of bituminous coal and asphalts has enabled a descriptive theory to be formulated which holds that the material is thermally split up into reactive fragments. Halogen acid catalyses the thermal splitting. The fragments then polymerize to form benzene-insoluble products or are stabilized by hydrogen to soluble products, the latter process being catalysed by tin. R. G. T.

1518. Patent. R. B. Mason, assr. to Standard Oil Development Co. U.S.P. 2,497,176, 14.2.50. Hydrogenation catalyst, for hydrogenation of unsaturated hydrocarbons, consisting of about 40–90% by weight of nickel sulphide promoted with thoria amounting to 0·5–15% by weight of the catalyst, and the balance alumina. C. F. S.

Polymerization.

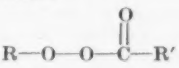
1519. Patents. W. L. J. deNie, assr. to Shell Development Co. U.S.P. 2,496,384, 7.2.50. Emulsion polymerization process for the manufacture of copolymers of homogeneous composition.

H. M. Guinot, assr. to Les Usines de Melle. U.S.P. 2,496,390, 7.2.50. Cyclic ether peroxide catalysts in the polymerization of conjugated diolefins.

I. Allen, W. R. Marshall, and G. E. Wightman, assrs. to Union Carbide and Carbon Corpn. U.S.P. 2,496,653, 7.2.50. A continuous process for the bulk polymerization of styrene.

J. R. Meadow, and A. A. O'Kelly, assrs. to Socony-Vacuum Oil Co. Inc. U.S.P. 2,496,669, 7.2.50. Copolymerization of thiophene with styrene in the presence of hydrogen fluoride to produce synthetic resins.

M. J. Roedel, assr. to E. I. du Pont de Nemours & Co. U.S.P. 2,497,323, 14.2.50. Process for polymerizing ethylene by heating at a temperature of 70–250° C in the presence of 0·005–2·0% based on the total weight of the reaction mixture, of a tertiary alkyl percarboxylate of the formula



A. J. Green, assr. to U.S. Rubber Co. U.S.P. 2,497,447, 14.2.50. Silica-sol catalyst in the emulsion polymerization of butadiene-1, 3 hydrocarbons.

S. S. Kurtz, assr. to Sun Oil Co. U.S.P. 2,497,458, 14.2.50. Butadiene–styrene copolymer " tackified " with *iso*-olefin–diolefin–styrene copolymer. C. F. S.

Chemical and Physical Refining.

1520. Trends in treating. C. W. Rippie. *Oil Gas J.*, 30.4.50, **48** (47), 110.—Various methods of sweetening gasolines are reviewed with reference to lead-susceptibility characteristics of the fuels. The effectiveness of sodium phenates in solutizer compounds is shown in a graph giving extraction of a series of pure mercaptans from *iso*-octane at 20° C. G. A. C.

Special Processes.

1521. Utilization of natural gas for conversion into nitrogeneous fertilizers. W. R. Pierce and C. W. Perry. *Oil Gas J.*, 4.5.50, **48** (52), 138.—The process for manufacture of nitrogeneous fertilizers using natural gas as a source of hydrogen and as a part

source of nitrogen as employed at the Cactus plant, Etter, Texas, of the Phillips Chemical Co., is described.

The natural gas available contains 71·8% methane and 16% hydrogen, and sulphur compounds are removed by the Girbitol and other processes. The gas from the sulphur-removal plant is mixed with steam and passed over nickel catalyst to give hydrogen, and air is added to the reformed gas.

Carbon monoxide and dioxide are removed, and the remaining gases reacted over iron catalyst to form ammonia, from which in turn is produced ammonium sulphate and nitrate.

Synthetic ammonia plants in the U.S.A. are listed. G. A. C.

1522. Mononitration of *p*-xylenes. K. A. Kobe and H. Levin. *Industr. Engng Chem.*, 1950, **42** (2), 352–6.—A study of process variables in nitration of *p*-xylene to mononitro-*p*-xylene has been made. 89% yield of mononitro-*p*-xylene was obtained at 30° C, with 30 min nitration, 3·0 D.V.S. (dehydrating value of sulphuric acid) and mol ratio of HNO_3 in *p*-xylene of 1·1. The effect of the four variables mentioned is shown graphically. Dealkylation did not occur in the experiments, and only small amounts of dinitro-*p*-xylene were formed. R. G. T.

1523. Nitration of nitro-*p*-xylene. K. A. Kobe and T. B. Hudson. *Industr Engng. Chem.*, 1950, **42** (2), 356–8.—A 95% yield of dinitro-*p*-xylene was obtained by nitration of nitro-*p*-xylene at 80° C, with 15 min nitration time, dehydrating value of sulphuric acid of 8·0 and 1·1 mol ratio HNO_3 : nitro-*p*-xylene. The product contains 60–80% of the 2 : 3-isomer and 40–20% of the 2 : 6-isomer. The 2 : 5-isomer and trinitro-*p*-xylene were not found in the products. R. G. T.

1524. Solutions of aluminium chloride as vigorous catalysts. A. W. Francis. *Industr. Engng Chem.*, 1950, **42** (2), 342–4.—Catalysis of the most difficult Friedel–Crafts reactions—alkylation of *iso*paraffins with ethylene, and isomerization of normal paraffins including butane—is made possible by use of solutions of $AlCl_3$ in organic solvents containing excess solute. The solutions show no induction period in the catalysis and more vigorous reaction is achieved. R. G. T.

1525. Thermal activation of attapulgus clay—effect on physical and adsorptive properties. W. S. W. McCarter, K. H. Krieger, and H. Heinemann. *Industr. Engng Chem.*, 1950, **42** (3), 529–33.—Data from present studies and previous work on natural and extruded samples of Attapulgus clay are presented. Chem composition, structure, X-ray diffraction patterns, thermal cleavage, surface area, true, apparent, and bulk densities, water-adsorption, properties, void vol, pore vol, and equivalent pore dia as a function of activation temp from 220° to 400° F are shown. Effects of change in structure during activation on water adsorption powers are discussed. Thermal cleavage is correlated with surface area and water adsorption. Extrusion serves to maintain surface area at high activation temps. R. G. T.

1526. Patents. E. N. Roberts and L. W. Mixon, assrs. to Stanolind Oil Co. U.S.P. 2,497,097, 14.2.50. Method of preparing stabilized organic sulphur compounds.

H. R. Snyder and J. M. Stewart, assrs. to Phillips Petroleum Co. U.S.P. 2,497,100, 14.2.50. A method of producing mercapto alkoxy thio-ether by reacting alkoxy thiol with olefin sulphide.

D. T. Rogers, assr. to Standard Oil Development Co. U.S.P. 2,497,138, 14.2.50. Method of dechlorinating sulphurized di*iso*butylene by heating with about 10% by weight of 2-ethylhexyl alcohol at a temperature of about 230–280° F for about 4 hr.

C. S. Carlson and H. T. Oakley, assrs. to Standard Oil Development Co. U.S.P. 2,497,150, 14.2.50. A three-step process for controlling foaming in an aqueous liquid-phase system, where alkyl chloride is prepared from hydrogen chloride and an aliphatic alcohol in the presence of a metal chloride catalyst, by first adding a small amount of lauryl sulphate, secondly, allowing reaction to proceed and foam-inducing substance to form, and thirdly, again adding lauryl sulphate.

C. A. Cohen, assr. to Standard Oil Development Co. U.S.P. 2,497,152, 14.2.50. A process for purifying petroleum sulphonates dissolved in an aqueous solution of a C_3 to C_4 monohydric alcohol, by treating with sodium sulphate.

C. T. Steele and E. A. Epps, assrs. to Standard Oil Development Co. U.S.P. 2,497,191, 14.2.50. A process for the production of *iso*butylene from an *iso*butylene fraction containing isomeric butene-1 and butenes-2 by contacting with sulphuric acid.

A. Farkas and A. I. Smith, assrs. to Union Oil Co. U.S.P. 2,497,349, 14.2.50. Production of alicyclic alcohols, by oxidizing in the liquid phase a saturated cyclic hydrocarbon with a gas containing free oxygen to produce an oxidate containing the hydroperoxide, and reducing the hydroperoxide to form alicyclic alcohol.

A. Clark, assr. to Phillips Petroleum Co. U.S.P. 2,497,761, 14.2.50. Synthesis of hydrocarbons by the interaction of H_2 and CO in the presence of an iron synthesis catalyst.

J. P. Bilisoly, assr. to Standard Oil Development Co. U.S.P. 2,496,265, 7.2.50. Describes a process for the synthesis of hydrocarbons by reacting CO and H_2 in the presence of fluidized subdivided catalyst consisting of a metal of the 8th group of the periodic system and amounts of a metal oxide, both constituents being associated with silica gel.

B. G. Gillespie, assr. to Standard Oil Development Co. U.S.P. 2,496,342, 7.2.50. A method of forming synthesis gas by contacting methane with CO_2 in presence of a copper catalyst on activated carbon.

B. G. Gillespie, assr. to Standard Oil Development Co. U.S.P. 2,496,343, 7.2.50. An improved process for hydrocarbon synthesis using a red-oxide-type fluid catalyst in contact with CO and H_2.

L. S. Kassel, assr. to Universal Oil Products Co. U.S.P. 2,496,396, 7.2.50. The manufacture of inorganic oxide spherical particles.

C. O. Hoover, assr. to Air Reduction Co. Inc. U.S.P. 2,496,536, 7.2.50. Desulphurization of crude and cracked petroleum distillates by introducing into the bottom of a column consisting of pieces of copper a vapour of an organic carboxylic acid to form a layer of copper soap, and then passing the distillate in vapour phase through the copper soap.

R. F. Derry, assr. to Union Oil Co. U.S.P. 2,496,621, 7.2.50. Catalytic hydration of olefins.

W. I. Denton and R. B. Bishop, assrs. to Socony-Vacuum Oil Co. Inc. U.S.P. 2,496,659, 7.2.50. The production of nitriles by contacting an olefinic hydrocarbon with ammonia in gaseous phase, at temperatures between 850° and 1075° F with a catalyst including a metal salt of molybdic acid and a metal salt of tungstic acid. C. F. S.

Metering and Control.

1527. Control equipment for use with non-luminous flames. Anon. *Mech. World*, 12.5.50, **127** (3304), 528.—Flame-control equipment is described which can be used where the flame is not sufficiently luminous to affect the ordinary photo-electric cell. Such is the case when burning methane, water gas, producer gas, or when using non-luminous types of burners with ordinary coal gas. This flame-control equipment works on the principle that flame is a partial conductor of electricity by virtue of the fact that the air in the immediate vicinity is ionized immediately and so becomes a conductor of electricity. A rod-type flame detector, electrically connected to the control unit, projects into the pilot flame, completing a circuit via the flame, to earth and closing a relay in the control unit which energizes an electrically operated gas valve, holding it in the " open " position. When the flame fails the circuit is broken and the valves close, shutting down the gas supply to the pilot flame and main burner. The unit may be connected to any type of electro-magnetic or motorized control valve, it is independent of thermal effects, instantaneous in operation, and does not suffer from fatigue.

A. S.

1528. Instrument engineering. G. S. Brown and D. P. Campbell. *Mech. Engng*, Feb., 1950, **72** (2), 124.—A general discussion is given of the growth of automatic control in recent years, and consideration is given to the design of such systems. A. S.

1529. Orifice-variable-area meter for small air flow measurement. H. G. Bourne and J. A. Wunderle. *Heating & Ventilating*, Apr. 1959, **47** (4), 77.—Increased attention has recently been given to air-sampling techniques and equipment. With this has come the necessity for measuring small air flows, and the paper describes an orifice–variable-area meter which permits such measurements to be made with conveniently portable equipment and with improved accuracy and dependability. The unit described weighs 1½ lb and has overall dimensions of 4 in × 6 in and overcomes the disadvantages of the mano meter, while retaining the desirable characteristics of the orifice meter. A. S.

Safety Precautions.

1530. Flameproof electrical equipment. J. R. Fawcett. *Mech. World*, 21.4.50, **127** (3301), 427.—Special regulations govern the design and manufacture of flameproof electrical apparatus, especially designed for use in explosive atmospheres. Such apparatus is tested at a Ministry of Fuel and Power testing station at Buxton before certificates of flameproofness are issued. The principles of construction of flameproof electrical apparatus and methods of test have been codified and are covered by B.S. 229. The paper describes a typical flameproof enclosure. A. S.

1531. Accidents through overfilling containers with liquefied gases. H. Aull. *Erdöl u. Kohle*, 1950, **3**, 195–6.—Details are given of the Ludwigshafen disaster of July 28, 1948, due to the explosion of a 30-ton rail tanker containing $(CH_3)_2O$. Car had been tested to 30 atm, and excessive v.p. can be excluded as reason of failure. Whilst cause of explosion was not conclusively proven, indications are that tank car was filled beyond the prescribed safety limit of 95% of capacity at 40° C. Resulting from the enquiry revised German safety code for liquefied-gas containers has been issued, calling, *inter alia*, for accurate measurement of capacity, an additional 5% ullage allowance in summer, protection from direct sunlight, weighing during filling. Dangerous accidents can also occur with smaller containers; examples of such with flasks containing NH_3 and C_3H_8 being quoted. V. B.

1532. Precautions in the use of compressed inflammable gases. R. Long. *Birm. Univ. Chem. Engr*, Oct. 1949, **1** (1), 18.—An account is given of an accident at Birmingham University when hydrogen issuing from a high-pressure cylinder was ignited without any apparent source of ignition. The precautions to be observed when handling compressed gases, and in particular inflammable gases, are listed. D. F. J.

1533. Fire Danger in Aircraft. R. H. Selby-Hele. *Airc. Engng*, Jan. 1950, **22** (251), 2.—In certain transport aircraft of recent vintage, the chances are now reasonably remote of a fire occurring in flight, while the prospects of extinguishing it are roughly in inverse ratio to the chance of it occurring. Unfortunately, all aircraft in use are not of recent vintage and there are, therefore, still far too few of these low fire-risk aircraft. The paper first describes and illustrates a number of fire-detectors and compares their relative merits. It is stated that the single-acting flame switch does its job remarkably well, but that what it does is not enough. On the other hand, many of the multi-acting-type detectors, which do all that is required, become unreliable owing to the susceptibility of their mechanisms to vibration. As far as extinguishing systems are concerned, there is agreement regarding the need for an engine-nacelle fire-extinguishing system unless it can be demonstrated that equivalent protection is provided by other means. Methyl bromide has been shown to be the most effective extinguishant. The causes of fires are then discussed in connexion with the question of fitting crash switches, and a number of specific crashes are mentioned to illustrate different causes of fires. Consideration is finally given to crash-proof tanks, fireproof materials, fluid lines, electrical conductors, etc., and the human element. A. S.

1534. Fire Resistant Finishes for Aircraft. J. A. Jones and R. V. Niswander. *Airc. Engng*, Apr. 1950, **22** (254), 109.—Due to occurrence of fires in commercial, passenger-carrying aircraft, studies have been made concerning improvement of ignition resistance of materials and subsequent propagation of fire. Often serious fires have developed as a result of propagation by materials which were not responsible for the original ignition of fire. Intensive effort has been made to reduce this fire hazard by development and application of protective coatings and finishes to vulnerable and combustible materials. This work led to the need for development of apparatus for testing and comparing such combustible materials under conditions simulating those of actual fire. One refractory coating material has been developed which is considered to provide satisfactory fire protection, but its weight and other disadvantages indicate necessity for further development work. Testing apparatus has been developed which permits evaluation of combustible materials, and the equipment provides also for the preheating of specimens at elevated temperatures before ignition, thereby permitting more thorough study of conditions of fire damage. Paper describes and illustrates the work done on the development of fireproof coatings and the elevated temperature-testing apparatus. A. S.

PRODUCTS.

Chemistry and Physics.

1535. Vapour pressure and the heat of sublimation of carbon II. P. Goldfinger and W. Jeunehomme. *Rev. Inst. franç. Pétrole*, 1949, **4**, 427–34.—Values found for the heat of sublimation of carbon (L_σ = 80–170) are discussed. Preliminary experiments are described in which the v.p. of C is measured by a method involving the observation of the intensity of an atomic beam of C coming from an opening in a graphite crucible heated to about 2000° K. Value of L_σ *ca* 80 k.cal are probably excluded, but confirmation is required to decide between values near 130 and 170 k.cal. Apparatus and technique are described. E. B.

1536. Adsorption of fatty acids on carbon blacks. Calculation of particle size. H. A. Smith and R. B. Hurley. *J. phys. & colloid Chem.*, 1949, **53**, 1409–16.—The adsorption of fatty acids on various carbon blacks has been studied. When acetic acid was adsorbed from soln in *cyclo*hexane the isotherm indicated that a unimolecular layer was readily formed on the carbon surface. Surface areas calc on the assumption that the cross-sectional area of the acid molecule is 20·5 sq. Å are generally in good agreement with areas calc using other methods. D. F. J.

1537. Sorption of GR-S type rubber by carbon black. I. Sorption from benzene solution by Graphon. I. M. Kolthoff and A. Kahn. *J. phys. & colloid Chem.*, 1950, **54**, 251–6.—The sorption by Graphon carbon black of GR-S type rubber has been investigated by shaking the carbon with the soln., centrifuging out the carbon black, and measuring the rubber content of the supernatant liquid. The relative visc at 30° C of this liquid was also measured in many cases. The amount of rubber sorbed remains unchanged after several hours of shaking whereas the intrinsic visc of the remaining soln changes slowly with continued shaking. It is probable that the lower-mol.-wt. fractions are sorbed faster than the higher-mol.-wt. fractions, but that as shaking continues the sorbed lower-mol.-wt. fractions are replaced by higher-mol.-wt. fractions. It was also found that the sorption at 50° C is not appreciably different from that at 30° C, and that the microgel fraction in rubber is not appreciably sorbed, whereas the sol fraction is sorbed completely. D. F. J.

1538. Nature of carbon black surfaces as revealed by adsorption studies. W. D. Schaeffer, M. H. Polley, and W. R. Smith. *J. phys. & colloid Chem.*, 1950, **54** (2), 227–39.—It is known that the particle size of a carbon black plays a large part in the reinforcement of rubber. To determine whether the reinforcing ability of carbon black is dependent solely upon particle size, heats of adsorption of a number of hydrocarbons on a variety of carbon blacks have been measured to indicate the magnitude of binding forces operative at the surfaces. The data indicates that the nature of the

carbon–rubber association may involve the unsaturation of the elastomer and the volatile matter in the carbon black. The max extent of the carbon–rubber interface is determined by the exterior particle surface rather than by the total surface as revealed by nitrogen adsorption. D. F. J.

1539. Surface areas of crystalline carbon and carbide powders as measured by the adsorption of nitrogen. F. E. Bartell and C. G. Dodd. *J. phys. & colloid Chem.*, 1950, **54** (1), 114–28.—Adsorption of nitrogen on crystalline graphite powders, a carbon black of moderate specific surface area, a finely divided diamond dust, and a finely divided silicon carbide has been measured using a modified Emmett apparatus. The carbide had the same crystal structure as diamond with half the carbon atoms replaced by silicon. It is concluded that either the method based on the simplified B.E.T. equation or the Harkins and Jura method may be applied to nitrogen adsorption data on non-porous carbon powders when the B.E.T. parameter n (representing the number of adsorbed molecular layers) is greater than *ca* 3 and the value of the B.E.T. const c (considered to involve the heats of adsorption and liquefaction) is less than *ca* 200. Otherwise the complete B.E.T. equation must be used. Since it is believed that the adsorbents used are crystalline and non-porous, the low values of n are not thought to be the result of adsorption in capillary pores. D. F. J.

1540. Thixotropic behaviour of carbon black in rubber. L. Mullins. *J. phys. & colloid Chem.*, 1950, **54**, 239–51.—Investigations are described into the behaviour of both unvulcanized and vulcanized rubbers compounded with carbon black, and the thixotropic build-up and breakdown of colloidal carbon black structures in the rubber are discussed. The properties of carbon-black–rubber systems depend upon the past history of the system, and may be changed both by working and by standing. Viscosity, plasticity, and stiffness can be defined, therefore, only when complications due to thixotropy are carefully controlled before and during the measurement. The theories of the reinforcement of rubber by carbon black are considered, and modifications are suggested to allow for thixotropic filler structure. D. F. J.

1541. Solubilization of polycyclic aromatic hydrocarbons. H. B. Klevens. *J. phys. & colloid Chem.*, 1950, **54** (2), 283–98.—The solubility of various hydrocarbons in water and their solubilization in potassium laurate solutions has been determined by shaking the hydrocarbon with the solvent, centrifuging and determining spectra of the solution in the region of the most intense band. It was found that soap micelles foam at a concn of 0·25M potassium laurate. Thus in all solutions this amount plays no part in solubilization.

The log of solubility (S) in water, and in soap solns at one particular concentration, of the condensed polycyclic hydrocarbons of 1–5 rings decreases linearly with the length (L) of the molecule. The differential change in the slope of S as a function of concn is seen to be largest with benzene, decreasing with increase in substitution through toluene, ethyl benzene, *n*-butyl benzene and becoming equal to zero for the condensed-ring polycyclics.

Solubilization data of the alkyl benzenes, naphthalene, phenanthrene, and dimethylaminobenzene are in accordance with the concept of the expanded hydrocarbons containing micelle since one or more molecules of hydrocarbon can be solubilized per micelle using a value of 150 soap molecules in each micelle. For polycyclics such as anthracene, and those with four or more rings a larger micelle than 150 molecules would be required. D. F. J.

1542. Preparation of some substituted benzophenones and benzohydrols. J. P. Picard and C. W. Kearns. *Canad. J. Res.*, 1950, **28B** (2), 56–9.—Six benzophenones were prepared through the extension of a method for the preparation of benzophenone dichloride by the action of carbon tetrachloride on benzene in presence of anhydrous calcium chloride, followed by hydrolysis using steam. The ketones were reduced to the corresponding hydrols by aluminium *iso*propylate. D. F. J.

1543. β-Aroyl-α, β-diphenylpropionic acids from diphenylsuccinic anhydride. J. A. McRae, R. A. B. Bannard, and R. B. Moss. *Canad. J. Res.*, 1950, **28B**, 73–82.—β-aroyl-α, β-diphenylpropionic acids are substances from which polynuclear structures

can be formed through reduction, cyclization, and dehydrogenation. They have been prepared from diphenylsuccinic anhydride by both the Friedel-Crafts', and by the Grignard reaction. Reduction of the acids was studied using the Clemmensen, high-pressure hydrogenation, and Meerwein Ponndorf methods. D. F. J.

1544. Experimental research on the mechanism of combustion of methane. R. Wildenstein and G. Pannetier. *Rev. Inst. franç. Pétrole*, 1949, **4**, 424–6.—Spectrographic examination has been made of the inner and outer cones produced when burning methane–air mixtures. Bands due to C_2 and CH radicals both had max intensity at about 10·8% CH_4, suggesting the inter-dependence between these radicals. Max intensity of the bands due to OH occur at $<10{\cdot}8\%$ CH_4. Combustion mechanism is discussed and existing hypotheses extended. E. B.

1545. Phase equilibria in hydrocarbon systems. (Volumetric and phase behaviour of methane propane system.) H. H. Reamer, B. H. Sage, and W. N. Lacey. *Industr. Engng Chem.*, 1950, **42** (3), 534–9.—Pressure–volume characteristics of four mixtures of methane and propane were studied between 40° and 460° F and pressures up to 10,000 p.s.i. Composition of coexisting phases was determined in the two-phase region above 40° F. Results are compared with earlier measurements on this hydrocarbon system made over a smaller pressure and temperature range. R. G. T.

1546. Isobaric heat capacities at bubble point (propene, *neo*hexane, *cyclo*hexane, and *iso*octane). C. E. Auerbach, B. H. Sage, and W. N. Lacey. *Industr. Engng Chem.*, 1950, **42** (1), 110–13.—For the above hydrocarbons isobaric heat capacities at bubble pt have been investigated from 60° to 80° F for propene, and from 80° to 200° F for the others. Calculation of heat capacities from directly measured isochoric values, using supplementary volumetric data, was made. Graphical tabular results are shown. R. G. T.

1547. Effect of temperature on density and refractive index. S. S. Kurtz, Jr., S. Amon, and A. Sankin. *Industr. Engng Chem.*, 1950, **42** (1), 174–6.—A summary of available data, including that of Eykman, showing that the Eykman equation represents experimental data for the effect of temp on density and refractive index of organic compounds over wide temp range. Object is to demonstrate the usefulness of the Eykman equation. R. G. T.

Analysis and Testing.

1548. Gas analysis—a review of articles published during 1947. C. A. Miller. *J. Inst. Petrol.*, 1950, **36**, 164.—A review of the literature relating to physical and chemical methods of gas analysis which appeared in the literature during 1947. Only conventional physical and chemical procedures are considered; spectroscopic methods of analysis are not included. A. R. W. B.

1549. Mass-spectrometry. C. W. Nutt. *Birm. Univ. Chem. Engr*, Oct. 1949, **1** (1), 8–17.—The principles of mass spectrometry are outlined, and the uses of the method are discussed. It is particularly useful in the analysis of hydrocarbon mixtures, a valuable aspect being the ability to distinguish between isomers of the same mol. wt. The mass spectrometer is also a useful tool for studying the mechanisms of reactions in which some of the atoms have been isotopically labelled to enable their behaviour to be traced. The mass spectrometer will possibly also be of use for analysis of gas samples from flames, since it is of sufficient sensitivity to detect and measure the free radicals which are present in very small concn. D. F. J.

1550. Photoelectric tricolorimeter. R. F. Denington. *J. Oil Col. Chem. Assoc.*, Mar. 1950, **33** (357), 137.—The tricolorimeter described is fast and easy in operation. The instrument uses three barrier-layer cells, each having a filter and galvanometer, so that the colour of the painted pattern is shown by the simultaneous deflection of the three galvanometers. The light source must be constant during operation. A frequency-compensating unit is added, which gives a good degree of stabilization but introduces the necessity of accurately matching the load. This is effected by feeding the lamp from a trapped transformer.

The output of filter photocell varies with colour of filter and with area of photocell exposed. Diagrams of instrument and circuit are given.

A table gives the statistical results of the examination of eighteen patterns daily for forty-five working days, and shows that the reproducibility and accuracy of the instrument is satisfactory for plant purposes. It is considered unsuitable for painted patterns showing less than 5% reflection in any one colour. Brief mention is made of the operation of the instrument. D. K.

1551. Practical application of the W. J. D. van Dijck [analysis] method in petroleum gas production. F. Schwietring. *Erdöl u. Kohle*, 1950, **3**, 176–8.—Examples of the calculations necessary for applying the method (fractional absorption) to the analysis of two- and three-component mixtures (C_3–C_4; C_3–C_4–C_5) and gasoline, whereby the initial absorption can be correctly distributed between the various components and the vol-% measured in both gas and liquid phases converted to wt-%. This paper is an addendum to the previous description of this method (*Oel u. Kohle*, 1942, **38**, 1194). V. B.

1552. Determination of paraffin [wax] in asphalt-containing petroleum products. H. P. Mojen. *Erdöl u. Kohle*, 1950, **3**, 167–71.—Dist method of paraffin estimation is unsuitable for asphaltic materials owing to the formation (experimentally confirmed) of paraffin by decomp of high-mol.-wt. asphalts. Methods of paraffin estimation in such materials are briefly reviewed, and detailed experimental technique of an analytical procedure suitable for a wide variety of pet products (asphalts, topped crudes, dist residues) is given. 10 g of material is melted and carefully mixed with 20 g bleaching earth at a temp ≯ 120–150° C. 6 g of mixture is Soxhlet extracted (24 hr) with "normal-benzin" followed by similar extraction with C_6H_6. First extract is evaporated, residue dissolved in 50 ml warm $CHCl_3$, and 18 ml EtOH added, hard ceresin being pptd. Filtrate evaporated, dissolved in 25 ml Et_2O, and 25 ml EtOH added, soft ceresin being pptd. Filtrate evaporated and paraffin therein determined by Holde method. In materials containing resins these will be pptd together with soft ceresin. Asphaltic matter in C_6H_6 extract is separately determined. Reproducibility of the method is good, and numerous analyses are given. V. B.

1553. Road vs laboratory knock ratings. J. B. Duckworth, G. T. Moore, and C. J. Domke. *Oil Gas J.*, 4.5.50, **48** (52), 142.—The history of the motor and research methods of determining knock ratings is given, and road-test equipment and technique described. A study of road-knock ratings for all fuels were determined by the modified Uniontown procedure, reference fuels being limited to primary standards: 2 : 2 : 4-trimethylpentane and *n*-heptane, and blends of the two.

Test fuels included 300 commercial motor fuels from the mid-west and eastern areas of the U.S.A.

From data produced it is stated that no sound correlation could be made; but by employing both motor and research octane numbers in conjunction with a curve (reproduced) plotted with road (20 m.p.h.) versus motor as a function of research rating, road knocking performance can be estimated with the probable accuracy indicated in a table. G. A. C.

Crude Oil.

1554. Refinability of West Texas crude oils. Anon. *Oil Gas J.*, 27.4.50, **48** (51), 194.—Analyses by Bureau of Mines of crude oils from important West Texas fields are tabulated.

Properties listed include specific gravity, colour, sulphur, visc at 100° F, and carbon residue, together with producing formation, age, and depth.

Percentages of gasoline and naphtha, kerosine, gas oil, lubricating-oil distillates, and carbon residue are also given. G. A. C.

Engine Fuels.

1555. A symposium on ignition. Anon. *Aeroplane*, 12.5.50, **78** (2031), 556.—The three papers presented at the European Ignition Conference organized by Lodge Plugs

Ltd., held in London, April 25 and 26, are summarized, and main points of the discussions are enumerated. In the first paper, " Trends in the design of aircraft sparking plugs," B. Hopps mentioned the use of heavy nickel electrodes in America, compared American and European plug-fouling statistics, and described various designs to overcome fouling and other defects. The second paper, by A. R. Griffin and J. G. Dawson, on " Spark plug performance as affected by fuel factors," emphasized that the use of T.E.L. in aviation petrols is essential. The three types of failure due to lead fouling, engine factors influencing lead deposition, pre-ignition, and improvements in plug performance were discussed. In his paper on " Fault diagnosis and location in aircraft engine ignition apparatus," D. F. Welch described and illustrated the use of the electronic ignition analyser for locating faults. These faults could be divided into two groups, those associated with ignition timing and with spark-voltage generation. The usefulness of the tester, its desirable features, and the necessary modifications to the ignition system to accommodate it were outlined. U. N.

1556. Augmented flames in half-open tubes. M. W. Evans, M. D. Scheer, L. J. Schoen, and E. L. Miller. *J. appl. Phys.*, 1950, **20** (1), 44–8.—A hydrocarbon–air mixture ignited by a spark at the closed end of a half-open tube generally has a max flame velocity of about 100 ft/sec. Flames with velocities approaching 1000 ft/sec have been obtained by placing in the path of the advancing flame a grid augmenter consisting of a sheet of metal containing holes with a trailing edge. High-speed Schlieren pictures have been taken at 4300 and 4400 frames/sec, and these, together with instantaneous pressure measurements, have been used to study flame structure and flow in the tube. The grid augmenter causes a mixing of burning and unburned gases which leads to an increase in the reaction surface which produces an increase in the rate of reaction per unit vol. This in turn results in the observed high velocities. The increase in rate of reaction may be of use in the design of furnaces, I.C. engines, and jet engines. D. F. J.

1557. Patent. F. V. Cook, assr. to Stanolind Pipe Line Co. U.S.P. 2,496,444, 7.2.50. A diesel fuel made up of sour kerosine distillate containing connate sulphur compounds and a corrosion inhibitor of about 0·002–2·0% by volume of formaldehyde to make the sour distillate non-corrosive. C. F. S.

Gas Oil and Fuel Oil.

1558. Boiler fuels in marine diesel engines. J. Lamb. *Motor Ship*, May 1950, **31** (364), 49.—The only effect of changing over from boiler fuel to diesel fuel or vice versa for vessels equipped in a similar manner to the *Auricula* is to alter slightly the revolutions of the engine. The only adjustment necessary when making such a change-over is to alter the speed-control lever; but for best results it may be necessary to alter slightly the commencement of the fuel-injection process. The annual saving in the fuel bill when operating on boiler fuel is approx £8000, consequently the initial outlay is regained after 7½ months operation on the cheaper fuel. A report from the chief engineer of the *Auricula* on engine-room performance after one year's service on the heavy fuel is reproduced.

The combustion of high-visc fuel with the existing plant in the *Auricula* proved successful, but there are mechanical conditions which can be improved upon, such as the condition of the under-piston supercharge spaces, which is contributing to the contamination of crankcase lubricating oil. Alterations in packings are discussed.

The condition of paints after three years' service on high-visc fuels has been investigated. Other aspects discussed include: cylinder lubrication, cylinder liner and piston-ring material, $K_2Cr_2O_7$ in cooling water, and results with 3000 sec fuel.

The equipping of the main engine of the *Paludina* to burn fuels having a visc up to 1500 sec Redwood 1 at 100° F, and its performance are also considered. D. K.

1559. Boiler oil for motor ships. Anon. *Motor Ship*, Apr. 1950, **31** (363), 26.—A summary of work accomplished in regard to four-stroke and two-stroke machinery, and technical details of the performance of boiler oil in service are given. The performance of *Auricula* was such that further ships of the Anglo-Saxon Petroleum Co.

have been equipped to operate on heavy oil. The performance of other vessels running on boiler oil is also discussed. Some tabulated data obtained during a period of 101 days' service of the *Auricula* are presented. Many leading diesel-machinery builders in this country are testing various grades of boiler oil with their machinery. A consideration of the financial saving in the use of boiler oil and particulars of methods of installation and cost involved in making necessary provision are given.

There are twelve literature references. D. K.

1560. Socony-Vacuum revamps lube—packaging facilities at Paulsboro. G. Weber. *Oil Gas J.*, 13.4.50, **48** (49), 78.—The reconversion of the packaging facilities necessitated by expansion of volume and varieties of products handled, cost $2,000,000.

Materials handling, barrel and can filling, compounding, and blending facilities were all redesigned.

Manhandling of barrels and cans has almost completely been eliminated, mechanical hands being installed, and manpower thus reduced 43%. G. A. C.

Lubricants.

1561. Sulphur-containing lubricating oil additives. H. Zorn. *Erdöl u. Kohle*, 1950, **3**, 171–5.—Two types of additives are considered, oxidn inhibitors and oiliness improvers. In the first group metal derivatives (Al, Cu, Pb, Sn) of di-*iso*butylphenol sulphide were examined. Sn product (metal content 10–15%) was most effective. Esterification improves oil solubility, and inhibitor used (0·04%) in all German aero-engine oils was a 50% solution of additive in spindle oil, containing 5% Sn, 3·2% S, and 0·9% Cl (latter from $SnCl_2$ used to make Sn salt). Method for detecting this inhibitor in oils, based on colour reaction of Sn with dithiol, is given. Ag derivative gave good laboratory results (diminution of peroxide formation and O_2 absorption), but was unsuitable owing to photochemical decomp. Second section deals with effect of various additives in light (approx 2 cs at 99° C) synthetic lub oils (mainly non-hydrocarbon) used for low-temp instrument lubrication. It is stressed that for evaluating visc properties at low temp (− 55° C) actual visc measurement is essential, mathematical visc/temp relationships ("*m*-value") not being adequate. Additives employed were mainly "Mesulfol" I and II (derivatives of amyl xanthate with SCl_2 and ethylene dichloride, containing 48–50 and 34–36% S respectively), used in amounts equivalent to 2% on the lubricant. Mesulfol II (unlike I) is non-corrosive to Cu. Physical properties of the Mesulfols are given. V. B.

1562. Problems in the development of efficient woollen-fibre lubricants. P. J. Martin. *Amer. Dyestuff Rept.*, 1950, **39** (7), 223.—The addition of a lubricant to wool stock is necessary to replace the natural wool grease removed from the fibres in the raw-stock scouring operation, and to facilitate the passage of the wool through the carding, spinning, and weaving operations. Typical self-emulsifiable wool oil consists of two main components, a mineral oil and emulsifiers. The mineral oil generally has a visc of 100 sec (S.U.) at 100° F, and varies in degree of refinement from a conventionally refined oil (light acid and clay treatment) to clay-percolated heavily acid-treated or solvent-refined product of superior light stability. Emulsifiers commonly used are blends of mineral-oil sulphonates, sulphated fats, and soaps of fatty acids or very small amounts of rosin fatty acids. Alcoholic materials, termed coupling agents, may also be present in the formulation. The oil sulphonates must be free from tarry components which would cause fibre-staining, and the fatty acid soaps should not be of the easily oxidizable types.

Without the addition of wool oil, fibre breakage, static electricity, etc., would make carding difficult. After the wool oil has discharged its functions in carding, spinning, and weaving, it must be readily removable in a normal washing operation. The properties considered in the evaluation of a wool oil are emulsifiability, emulsion stability, scourability, lubricity, effect on leather condenser tapes and aprons, resistance to discoloration on the fibres under the influence of light, resistance to rancidity and autoxidation, antistatic properties, anti-corrosion properties, stability to freezing, and brightness or clarity. Routine procedures and specialized test methods and apparatus used in the laboratory development of wool oils are discussed, and the results of a comprehensive evaluation programme at the Lowelle Textile Institute are

quoted. This study, primarily of self-scouring wool oils, produced significant data on carding, spinning, weaving, and wet finishing which would not have been readily obtainable in commercial mills. C. N. T.

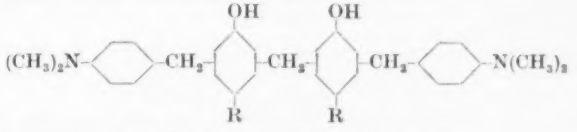
1563. Characteristics of greases as related to antifriction bearing applications. E. S. Carmichael and R. C. Robinson. *Mech. Engng*, Feb. 1950, **72** (2), 137.—The principal characteristics of greases, which are usually considered in recommending soap-thickened lubricants for antifriction-bearing applications, are discussed under the following headings: (i) consistency, (ii) apparent viscosity, (iii) structural ability at elevated temperatures, (iv) resistance against separation of oil, (v) chemical stability, (vi) water resistance and rust-preventive properties, (vii) film strength. A. S.

1564. Maintenance of antifriction bearings. J. M. Bruening. *Mech. Engng*, Feb. 1950, **72** (2), 142.—Cleanliness is the chief requirement in the maintenance of anti-friction bearings. The precautions taken to ensure clean bearings are listed, and methods are suggested for washing bearings when they have been removed from machinery during overhaul. A. S.

1565. Patents. A. J. Morway, A. Beerbower, and J. C. Zimmer, assrs. to Standard Oil Development Co. U.S.P. 2,497,133, 14.2.50. Process for preparing lubricating grease composition highly stable in severe mechanical working, by combining about 15–20% by weight of lithium stearate, about 1% of zinc naphthenate, 77·5–83% of di-2-ethyl hexyl sebacate, and 1–1·5% of antioxidant.

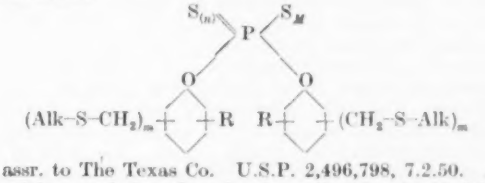
H. D. Hartough and S. J. Lukasiewicz, assrs. to Socony-Vacuum Oil Co. Inc. U.S.P. 2,497,067, 14.2.50. A lubricating oil containing a thenylamine to effectively reduce corrosion of bearings.

H. G. Smith, T. L. Cantrell, and J. G. Peters, assrs. to Gulf Oil Corp. U.S.P. 2,497,099, 14.2.50. A lubricating-oil composition containing a substantially neutral polyvalent metal salt of a compound having the formula



R is an alkyl radical having from four to twelve carbon atoms.

L. A. Mikeska, assr. to Standard Oil Development Co. U.S.P. 2,497,132, 14.2.50. A lubricating oil comprising a mineral-lubricating-oil base and an oxidation-inhibiting compound of the structure



H. D. Kluge, assr. to The Texas Co. U.S.P. 2,496,798, 7.2.50. A rust-inhibiting lubricating composition consisting of an oleaginous liquid and 0·01–3·0% by weight of a tertiary dodecyl thiosuccinic acid. C. F. S.

Bitumen, Asphalt, and Tar.

1566. Road research in the United Kingdom. K. E. Clare. *African Rds & Transport*, Jan/Feb. 1950, **8** (1), 17.—The D.S.I.R. Road Research Laboratory, Harmondsworth, comprising chemists, engineers, and physicists, investigates the various aspects of road problems. Bitumen and tar surfacings are examined in the laboratory and by practical trials. Soil problems, including foundations and stabilization processes, are dealt with, as are concrete roads, and aggregates for use in bituminous road work. Other aspects of the work of the Road Research Laboratory include investigation into

machinery employed in road work, road safety, and the provision of an information service. R. H.

Special Hydrocarbon Products.

1567. Livestock pests bow to chemicals. H. H. Schwardt. *Chem. Ind.*, Jan. 1950, **66** (1), 60.—For some time livestock men have been becoming more and more alive to the potentialities of such insecticides as D.D.T., benzene hexachloride, Toxaphene, etc. Dusts, wettable powders, and emulsifiables are the most useful form in which these toxic agents can be applied to livestock.

The latest development in this field is a product known as Lindane, which contains 99% γ-benzene hexachloride. It is effective against most insects which attack livestock and infest livestock quarters. It has the distinct advantage that it can be used on dairy cattle at dosages sufficient to kill mange mites and lice, but produces only negligible milk residue. However, the cost is very high, and therefore, at the moment, the popularity of the product is not great.

At the present time, Toxaphene, chlorinated camphene, is attracting attention due to its low cost and its ability to control cattle, hog and goat lice, sheep ticks, and fleece worms. O. M.

1568. Latest carnauba wax study. C. J. Marsel. *Chem. Ind.*, Feb. 1950, **66** (2), 216.—In order to bring information on the physical and chemical properties of carnauba wax up to date, an extensive investigation, involving an examination of the various methods available, has been carried out on fifty-six samples of the wax. These waxes were separated into four groups, namely :—

(1) # 1 yellow and # 2 yellow. These are prime waxes, obtained by cutting the smaller and less mature leaf.

(2) Canhypa and North Country # 2.

(3) Fatty Grey and North Country # 3. This represents wax obtained by cutting the mature leaf.

(4) Chalky wax. This represents wax obtained by adding water during the melting process.

The following properties were estimated : dirt and moisture ; flash point ; melting point ; acid number ; saponification number ; iodine number ; emulsification.

This work suggests that further research to characterize these waxes should be directed towards the determinations of the effect of variables upon emulsification, and the development of sensitive tests for the detection of various possible adulterants. O. M.

Derived Chemical Products.

1569. Effectiveness of detergents in removing soil from a cotton and a wool fabric. M. S. Furry and V. I. McLendon. *Amer. Dyestuff Rept.*, 1950, **39** (7), 209.—Printed cotton and wool cloths were used as test fabrics for evaluating effectiveness of ten soaps and twenty-seven synthetic detergents in removing soil under standardized conditions, by means of changes in light reflectance measured with a photo-electric colour-difference meter. The index values for the soaps in distilled water were about the same with the two fabrics, whereas for the synthetic detergents the values with wool were generally higher than those with cotton. The order of efficiency of the synthetic detergents in distilled water was different for the two fabrics, the alkyl aryl sulphonates being much more effective in removing soil from wool than from cotton, while the unbuilt non-ionic detergents were the least effective with wool but fairly effective with cotton. The built non-ionics were among the most efficient of the detergents tested with wool. The alkyl sulphates, the alkyl aryl sulphonates, and the non-ionic detergents were about as efficient in hard as in distilled water. The soaps and the remaining synthetic detergents removed less soil in hard than in distilled water. C. N. T.

Miscellaneous Products.

1570. The paint industry in Germany during the period 1939–1945. B.I.O.S. Rept No. 22. 1. Paints, varnishes and printing inks. N. Fisk and H. W. Bowron. *Paint Technol.*, Apr. 1950, **15** (172), 151.—The report is reproduced in full. German work on

paints, printing inks, pigments, oils, and miscellaneous media, *i.e.*, fatty acids and waxes, driers, and coating resins, is described. Thirteen figures reproduced include seven flow sheets. Article to be continued. D. K.

1571. The opacity of white pigments with special reference to titanium dioxide. E. G. Rutter. *Paint Manfr*, May 1950, **20** (5), 161.—Equations have been deduced showing the relationship between reflectance and concentration of pigments. By means of a photo-electric intergrating sphere photometer it has been shown that those equations due to Smith and Amy are simultaneously true provided the found values of reflectance are corrected for the gloss of the varnish layer lying over and under the pigments. Films were prepared on cellophane, so that a layer of pigment was between layers of cellophane. For some measurements many layers were used, but it is believed only the boundary layers are significant. Equations show the gloss correction. Applications of these measurements to the determination of the commercial value of white pigments is discussed. Many photographs, diagrams, and tabulated data are included.

There are thirteen literature references. D. K.

1572. Relationship between dielectric properties and the physical conditions of drying-oil varnish films. W. M. H. Schulze. *Schweiz. Arch. Ang. Wiss. Tech.*, 1950, **16**, 88–93.—Varnishes (linseed oil, tung oil, " asphalt varnish ") showed decrease (approx 0·03 to 0·004) of p.f. (tan δ at 800 cycles) with increasing firing time and/or temp. Excessive drying can, however, cause eventual rise in p.f. due to decomp. Dielectric const tends to increase with extent of drying, and the capacity/temp relationship is strongly influenced by duration of firing. V. B.

1573. Compatibility of varnish—making resins. H. W. Chatfield. *Paint Mnfr*, Apr. 1950, **20** (4), 121.—A resin which is not permanently compatible on storage can lead to a number of defects. These are listed.

White spirit was found to be the best solvent for use in assessing compatibility of resins for incorporation into air-drying compositions, especially those applied by brushing. The usual white-spirit-tolerance test consists in adding white spirit to a previously-prepared concentrated solution of resin, until the resin shows the first signs of precipitation. Some figures obtained for various resins are given. The initial white-spirit tolerance of some resins can diminish to such an extent on ageing that it could cause considerable trouble during storage of manufactured products. A method for determining the permanent white-spirit-tolerance figures for a varnish-making resin is outlined. This method is regarded as being more satisfactory than the direct-titration method. The article is to be continued. D. K.

1574. Stress-strain curves for fatigued rubber. D. F. Stedman. *Canad. J. Res.*, 1950, **28F** (2), 31–49.—The extension curves of natural rubber, vulcanized to soft " gum " rings, are in two parts, the second part developing only after previous severe extension. Since the equation for both parts of these extension curves is of identical form, although hysteresis occurs in one part and not in the other, it is suggested that the basic cause of elasticity of rubber cannot be considered to be related to any molecular-arrangement factors, but must be of a kinetic nature. It is shown that if it is assumed that the rubber chain is vibrating, and the tension in the chain restricts the vibration, the forces developed would be quite adequate to explain the elasticity. D. F. J.

CORROSION.

1575. Theory of corrosion for engineers. W. L. Orr and H. A. Stafford. *Chem. Education*, Apr. 1950, **27** (4), 202.—The purpose of the paper is to give engineering students a brief survey of the theory of corrosion and its application, since most text-books on chemistry and metallurgy are too brief on this subject, while more complete works on corrosion are too lengthy. The electrochemical theory of corrosion is briefly discussed, and a table is given showing values of the oxidation potential of the various metals. A further table gives the galvanic series of metals and alloys. Factors in-

fluencing corrosion are then discussed, together with the use of the ferroxyl indicator, which demonstrates the effect of strain on corrosion. This indicator is an agar-agar gel containing potassium ferricyanide and phenolphthalein. The ferricyanide ion reacts with the Fe^{++} ions as they are formed and migrate into the gel, forming a blue colour due to $Fe_3[Fe(CN)_6]_2$, and the phenolphthalein forms a red colour in the presence of hydroxyl ions formed by the cathodic reaction. The paper finally describes various methods of controlling corrosion such as surface coatings, cathodic protection, inhibitors and passivators, metal purification and alloying, and alteration of the environment. A. S.

1576. Corrosion tests for soluble oil dispersions. (By) Cutting Oil Panel of Standardization Sub-Committee. No. 6—Lubricants. *J. Inst. Petrol.*, 1950, **36**, 148.—The problems involved in drawing up a corrosion test for cutting oils are discussed. The tentative specification for such a test, I.P. 125/49(T), is put forward, together with a summary of the work undertaken by the I.P. Cutting Oils Panel between 1945 and 1948. A. R. W. B.

1577. Patents. M. I. Moyer and J. M. Hersh, assrs. to Cities Services Oil Co. U.S.P. 2,496,354, 7.2.50. A process of preventing corrosion of metals in contact with brines containing corrosive sulphur compounds by adding a small amount of melamine to the brine.

M. I. Moyer and J. M. Hersh, assrs. to Cities Services Oil Co. U.S.P. 2,496,594, 7.2.50. Process of preventing corrosion of metals in contact with oil-well brine by the use of formaldehyde/ammonia corrosion-inhibitor compositions.

M. I. Moyer and J. M. Hersh, assrs. to Cities Services Oil Co. U.S.P. 2,496,595, 7.2.50. A formaldehyde corrosion-inhibitor composition comprising an aqueous solution of formaldehyde and hexamine, in the ratio of from about 3–40 parts formaldehyde to one part hexamine by weight.

M. I. Moyer and J. M. Hersh, assrs. to Cities Services Oil Co. U.S.P. 2,496,596, 7.2.50. A formaldehyde corrosion-inhibitor composition comprising an aqueous solution of formaldehyde and an amino-reactive component from the group consisting of alkylamines, alkanol amines, aryl amines, alkylamino phenols, alkylamino phenylene diamines, heterocyclic amines, and ureas. C. F. S.

Engines and Automotive Equipment.

1578. Diesel engine propulsion of cargo liners—development and maintenance. A. G. Arnold. *Trans. Inst. mar. Engs*, Apr. 1950, **62** (4), 133.—The paper shows the progressive development of the marine diesel engine from 1923 up to the present time. The author has limited his remarks to vessels and engines with which he has had close association during the last quarter of a century, and the engines described are those adopted by Messrs Alfred Holt & Co. for their cargo liners since 1923. The paper describes the changes which have taken place in marine-diesel-engine design—from the early four-stroke, single-acting to the latest two-stroke, double-acting engine—and it is shown how the space occupied by the engine and its weight have been reduced during this period. Also described are methods of lubrication and cooling-water systems, and the reduction in fuel-oil consumption over the period in question is discussed. Numerous drawings of the different engines and engine parts dealt with are included. A. S.

1579. A new diesel engine indicator. Anon. *Motor Ship*, May 1950, **31** (364), 69.—The article describes a Dobbie McInnes instrument for registering peak pressures. I. G. B.

1580. Gas turbine testing. A. C. Lovesey. *Flight*, 6.4.50, **57** (2154), 427.—This is a précis of the author's paper to the R.A.E.S. on modern methods of testing aero engines and power plants. Pertinent comments are made on the testing of combustion chambers and the effect of the discharge on turbine blades. I. G. B.

1581. The outlook for ceramics in gas turbines. W. H. Duckworth and I. E. Campbell. *Mech. Engng*, Feb. 1950, **72** (2), 128.—Part of the research on ceramics is directed specifically towards gas-turbine applications, and much of the remainder is in some way related to such uses. The research is part of the effort directed towards the discovery, development, or refinement of materials to meet temp requirements peculiar to propulsion of high-speed, high-performance aircraft and guided missiles. The investigations pertinent to gas turbines have been rather thorough on most of the refractory oxides singly, and on many combinations of oxides, but there is room for much more research on combinations of oxides. Consideration is given to the use of ceramic bodies as rotor blades, stator blades, and combustion chambers, and references are given to work carried out on these applications. Research has also been carried out on the development of ceramic coatings for metals, and these coatings seem particularly attractive for immediate use. The primary purpose of the coatings, presumably, is to seal the metal surface against corrosive attack, and secondarily to provide thermal insulation. Not much can be expected from them as insulators, as they must be thin in order to be tough and adherent. With co-operation between ceramists and gas-turbine engineers, gas turbines with higher operating temperatures, longer life, or both, and perhaps lower weight might be possible in the not too distant future. A. S.

1582. High-power two-cycle sleeve-valve engine for aircraft. G. F. Hiett and J. V. B. Robson. *Aire Engng*, Jan. 1950, **22** (251), 21.—The paper contains a description of the development of the two-cycle, petrol-injection, research units built and tested in the laboratory of Messrs Ricardo & Co. Ltd. The sequence of events leading up to the programme of research is first described, followed by the history of the development of suitable single-cylinder research units. The outstanding design features of these units are described. A. S.

1583. Petrol injection. R. Barrington and E. W. Downing. *Auto Engr*, Apr. 1950, **40** (526), 153.—The paper describes the results which have been obtained in a series of experiments, the purpose of which was to examine the claim made for improved results in fuel consumption and max power which could be obtained by substituting a petrol-injection system for a carburettor. A petrol-injection system was evolved incorporating as many as possible of the features which seemed initially desirable, and others which became apparent during the development. It was bench tested in conjunction with a pre-war engine and run on the road for 20,000 miles. Later, work was also carried out on a post-war engine. A detailed description is given of the fuel-injection system used, the engine tests and results obtained. These show that the application of petrol injection to two high-speed engines of approx 1½ litres capacity, but of widely differing characteristics, has in each instance produced an appreciable improvement in performance. It remains with the manufacturer or user to decide whether the many advantages make petrol injection a worth-while proposition. A. S.

1584. Tracked vehicles. W. Steeds. *Auto Engr*, Apr. 1950, **40** (526), 143.—An analysis is given of the factors involved in the steering of tracked vehicles. From the point of view of steering, tracked vehicles may be divided into two groups: (1) those employing laterally flexible tracks, and (2) those with laterally rigid tracks. The laterally flexible track has two degrees of flexibility and this necessitates the use of a double pivot or universal-joint type of connexion or a ball-and-socket joint. Such joints are expensive to produce, and this is a very serious drawback. In addition, it has been found to wear more rapidly and to be more prone to coming off the sprocket than the laterally rigid track. The paper contains mathematical analyses of the kinematics of steering, elementary dynamics of turning a vehicle and steering dynamics. A. S.

1585. Patents. J. E. Vallerie. U.S.P. 2,496,362, 7.2.50. Oil films are made on the interior surfaces of I.C. engines, prior to turning the engine over, by injecting atomized oil under pressure into the engine and drawing the atomized oil through the engine by suction.

L. E. Endsley and J. E. Justus, assrs. to Fairbanks, Morse & Co. U.S.P. 2,496,458, 7.2.50. I.C.-engine fuel-control means.

F. L. Bartram. U.S.P. 2,496,768, 7.2.50. A fuel distributor for diesel engines.
C. F. S.

MISCELLANEOUS.

1586. National annual survey of commercial aviation gasoline, October 1949 production. O. C. Blade. *U.S. Bur. Mines Rep. Invest.* 4664. Mar. 1950.—Inspection test data of commercial aviation gasoline grades 80, 91/98, 100/133, and 115/145, produced by sixteen manufacturers in the U.S. during Oct. 1949, are recorded in comparison with those produced in 1947–48.

Trends of the gasoline characteristics are described and shown in graphs for the same periods. No significant differences are revealed. Test data of eleven aviation gasoline samples of the production for military use are also given. W. H. C.

1587. Chemical filters. S. A. Miller. *Chem. Ind.*, Jan. 1950, **66** (1), 38.—This is a critical survey of the various types of filter available, and includes references to cases where particular filters are specially applicable.

The filters considered are classified under the following headings: (1) cake filters; (2) clarifying filters; (3) special filters.

There are also sections dealing with selection of a filter for particular purposes, and with filter bases and aids. O. M.

1588. New flameproofing agents more durable and efficient. J. M. Fain. *Chem. Ind.*, Mar. 1950, **66** (3), 360.—Recent legislation in the U.S. has led to greatly increased interest in flameproofing agents for fabrics and wood.

During the war, a water-resistant and a water-soluble formulation were developed for proofing clothing. The active ingredient in the former was antimony oxide, while that in the latter was a mixture of borax, boric acid, and diammonium phosphate. These were applied by steeping the fabric in the proofing formulation or by spraying or brushing.

The durability of such formulations depends on their resistance to water, and lately the following compounds have been developed for flameproofing purposes: ammonium and urea sulphates, borophosphate resins, alkyl and aryl phosphates, borates, etc. The most recent development is a product known as "Erifon," which is a solution of titanium and antimony salts.

The main stipulations which flameproofing materials must meet, if they are to be used with textiles, are: (1) they must not reduce the tensile strength of the cloth appreciably; (2) they must not change the appearance and hand characteristics of the fabric; (3) they must be easy to apply; (4) they must be economical; (5) they must be non-toxic; (6) resistance to leaching-out must be as high as possible.

In the case of wood, house paints containing chlorinated paraffins have been found to be very satisfactory.

The method of action of these flameproofing agents can be explained in several ways, viz., modification of the cellulose molecule either before or at the end of combustion, but probably several of them contribute simultaneously to the final result. O. M.

1589. Chemical engineering and the petroleum industry. F. H. Garner. *J. Inst. Petrol.*, 1950, **36**, 141–7.—The influence of the petroleum industry in the development and application of chemical-engineering principles is traced. A. R. W. B.

1590. How to prepare technical data sheets. M. H. Baker. *Chem. Ind.*, Jan. 1950, **66** (1), 34.—Since the technical data sheet acts as an introduction of a new product to potential users, careful consideration must be given to its form and to its contents if it is to serve its purpose in developing sales.

In form, it should be attractive, but not flamboyant, while its contents should be laid out in logical order giving properties and suggested applications in a clear and concise manner. The author suggests the following order for the data included in the sheet: (1) name of company and product; (2) date of issue; (3) availability of samples,

prices; (4) description and formula of product; (5) possible uses; (6) detailed physical and chemical properties; (7) suggested formulations and technological data; (8) waiver of responsibility for patent infringement.

The impracticability of holding up publication of technical data sheets pending availability of further information about the product is pointed out. The sheets should be so edited that it is possible to issue addenda at a later date without rendering the final publication disjointed. O. M.

1591. How to change a valve on a full tank. E. Sterrett. *Chem. Ind.*, Jan. 1950, **66** (1), 33.—Describes simple devices which can be used when it is desired to change or add a gate valve at the bottom of a full tank without emptying the tank. A similar procedure can be adopted when it is desired to work on lines of valves connected to tanks which have contained inflammable liquids, but have not been de-gassed. O. M.

1592. Modern marine fuel and diesel oil prices. Anon. *Motor Ship*, May 1950, **31** (364), 69.—These are listed in shillings or dollars per ton at various ports throughout the world. I. G. B.

1593. Patents. P. K. Frolich, assrs. to Standard Oil Development Co. U.S.P. 2,497,123, 14.2.50. A self-sealing liquid-fuel container comprising an outside supporting fabric, next a one-ply layer of material consisting of natural rubber, butadiene styrene synthetic rubber, polybutadiene rubber, high-mol.-wt. polymerized olefins and high mol.-wt. *iso*-olefin–diolefin copolymers, and on the inside a fuel-resistant layer comprising a plurality of laminæ made of rubber compositions.

B. B. Corson and G. A. Webb, assrs. to Koppers Co. Inc. U.S.P. 2,495,700, 31.1.50. A silica–alumina–nickel dehydrogenation catalyst.

C. F. S.

BOOK REVIEWS.

Flow Measurement and Meters. A. Linford. London: E. & F. N. Spon Ltd., 1949. Pp. xx + 336. 30*s*.

In this book the object has been "to give a general picture of the art of metering the flow of fluids through both open and closed conduits," and in this the author has succeeded admirably. In seven chapters, headed respectively "Mechanical flow meters," "Differential pressure flow meters," "Shunt flow meters," "Variable aperture flow meters," "Open channel flow meters," "River flow gauging," and "Telemetering," the author deals with the theory, installation, and mechanism of operation of many types of meters available to industry. Each chapter is subdivided for easy reference, and the text is well illustrated by numerous diagrams and line drawings. The chapter on differential flow meters is naturally the largest in the book, and is extremely well presented. Much information is given which was previously available only in the manuals of the instrument manufacturers.

Whilst the book will be of particular value to instrument engineers and plant operators it will also be of interest to chemical engineers, production engineers, and to mechanical engineers and others. Although the mathematical theory may be required only by the specialist in instrumentation, the details of operating mechanism, installation, and the comparison of various types of meters will be found of general interest. The book is well produced, and if the future texts maintain the standard set in this book the series will be a valuable addition to mechanical engineering literature. F. M.

Natural Gas and Natural Gasoline. R. L. Huntington. New York: McGraw-Hill Book Co. Inc., 1950. Pp. vii + 598. 68*s*.

This book, written by the Professor of Chemical Engineering, University of Oklahoma, is primarily intended for engineering students, of graduate standard, taking courses dealing with the production of natural gas from crude oil, condensate, and dry gas fields, and the manufacture of natural gasoline. However, it has a much wider appeal, as a great deal of practical data outside the scope of the ordinary text-book is included. This material should prove of interest to engineers engaged in process and equipment design.

It begins with the history of natural gas in America, starting in 1870 when a wooden pipeline was laid from a dry-gas well into Rochester, N.Y.

Many of the sections, including those on the estimation of gas reserves, gas gathering, processing, and cycling, have been based on experience obtained in the U.S. The determination of cycling efficiencies is the subject of a thesis by R. L. Hock, who surveyed the Cotton Valley (Louisiana) gas-condensate reservoir.

Fundamental principles of distillation, fractionation, and absorption are used to resolve some of the problems encountered in plant design and operation. The passage on absorption is written mainly around the use of bubble-tray absorbers. An abstract of published data on froth heights and pressure differentials in a bubble plate column has been included.

A chapter on gas dehydration has been written by Professor L. S. Reid, who favours the use of glycol–water solutions and solid absorbents such as activated alumina and activated bauxite. Physical data of these absorbents are given, as well as a critical survey of problems encountered in plant operation. Silica gel has been omitted from the survey, on account of its susceptibility to poisoning by certain of the heavier hydrocarbons found in natural gas.

Conjointly with other workers, the author was engaged in a mathematical research project on the design of high-pressure pipelines. The outcome of this work is described in the text. In addition to theoretical considerations, the project takes into account the economics of laying and maintaining long-distance pipelines.

Storage and transportation of natural gas and gasoline are fraught with difficulties, and Professor Huntingdon discusses many of them. The storage of natural gas, butane, and propane in depleted gas reservoirs has been given special treatment.

Excerpts from two published papers, of which he was part author, describe the results of laboratory studies on the unsteady flow of natural gas, butane, and propane through sand of known porosity and permeability.

In order that the student may obtain a thorough working knowledge of the subjects, a number of problems are worked out in detail and a number are set for the student to work out. It is hoped that in solving these, the student will also gain confidence in himself before he tackles the more difficult tasks of developing new processes and designing plant on which little published matter is available. The author has been very generous with these problems; the theory of natural gasoline, for example, is supported by as many as fifteen pages of them. It would have been better, however, if answers had been given to more of the problems left to the student, particularly those involving calculations.

The book ends with appendices on the physical properties of hydrocarbons, commercial specifications for natural gasoline, a standard form of contract for purchasing casinghead gas, standard compression and charcoal tests for determining the natural gasoline content of natural gas, and the N.G.A.A. procedure for the analyses of saturated hydrocarbon gases by low-temperature fractional distillation.

Each chapter is followed by a good relevant bibliography. The book is well illustrated with diagrams and is admirably set out. K. R. G.

Physical Principles of Oil Production. M. Muskat. New York: McGraw-Hill Book Co. Inc., 1949. Pp. xv + 922. 127*s*. 6*d*.

This book may be broadly divided into four main sections; the first presents general background material and summarizes the available information on the fundamental physical properties of petroleum fluids and reservoir strata. The phase behaviour of one-component, various two-component, and finally multi-component hydrocarbon systems is explained, followed by a review of the methods available for the prediction of the volumetric and phase behaviour of hydrocarbon systems and a discussion of formation volumes; retrograde phenomena are also discussed. Some information is presented on the viscosity of hydrocarbon systems and interfacial tensions between reservoir fluids, and several charts indicating the order of variation of these properties in oil reservoirs are reproduced from the literature. In the concluding chapter of the first section the types of measurements of porosities, permeabilities, and fluid saturations are reviewed, and the interpretation of these data is discussed.

The second section consists of the formulation of the hydrodynamical equations for homogeneous fluid-flow systems. After explaining the basic hydrodynamical equations the author considers individual well problems in isotropic (uniform) strata, and derives equations defining radial and spherical flow conditions, combinations of these two (c.f. partial penetration of oil sands), and conditions of flow through slots and casing perforations. The mechanism of water coning is also discussed. The treatment is then extended to anisotropic formations, and based upon this, special cases, such as the effect of a sanded liner on the productive capacity of a well, are considered.

In the third section the principles developed for homogeneous systems are extended to heterogeneous systems. The fundamental concepts of effective and relative permeability are expounded at length as a foundation upon which this extended treatment can be based. Prior to the treatment of the dynamical case the author also discusses the distribution of a heterogeneous system of fluids under static equilibrium conditions (as in a virgin reservoir) and the effect of capillary forces. A chapter on steady-state heterogeneous-flow systems and the productivity index completes the basic fundamental treatment of the dynamical problems as a pre-requisite to the study of actual reservoirs.

The fourth section on reservoir performance opens with a discussion of the various energy mechanisms responsible for the movement of oil into a well. The author then explains the principles of material balance equations as applied to oil reservoirs, since the treatment of reservoir performance has to be based, not only on the energy requirements necessary to overcome all the frictional resistances to flow considered in the preceding sections but also on the law of conservation of matter with respect to the gross fluid contents of the reservoir as a whole. Applications of the material

balance equation to cases of no water influx and of partial water drive are then considered. All the foregoing principles are applied at length to the reservoir performance of gas drive, water drive, and condensate reservoirs, and to secondary recovery practices.

The author concludes his book with a chapter on well spacing, recovery factors, and recoverable reserves.

Throughout the book the author emphasizes that the theoretical material presented refers to idealized systems and that whilst the fundamental physical principles involved are quite well established the analytical treatment of practical systems can only be solved at present by the introduction of drastic simplifications. The author feels, however, that if the limitations of the theory and the nature of the modifying factors obtaining in practical systems are given proper consideration, then the theoretically derived production histories should provide a reasonable basis for planning the development and operation of actual reservoirs.

This book is not a handbook of instructions for field operation but an exposition of material which is in an active state of flux, written for the reservoir engineer who desires to extend his knowledge of the fundamental physical processes occurring within an oil reservoir and for the purpose of stimulating and encouraging further research and study of the subject.

It is, in fact, a fully comprehensive treatise expounding practically everything at present known relating to reservoir engineering. The subject matter has been dealt with by Dr Muskat in an extremely interesting and informative manner.

R. B. S.

BOOKS RECEIVED.

Bibliography of Publications and Reprints of the Safety in Mines Research and Testing Branch. Sheffield : Ministry of Fuel and Power, 1950. Pp. 34.

A useful bibliography of the publications of the Safety in Mines Research and Testing Branch of the Ministry of Fuel and Power. Copies are obtainable from the Branch at Portobello Street, Sheffield, 1.

Phase Relationships in Oil and Gas Reservoirs. D. L. Katz. College Station, Texas : Agricultural & Mechanical College of Texas, 1949. Pp. 63.

Published as Bulletin No. 114 of the Texas Engineering Experiment Station, this is a series of lectures presented by Prof. Katz at a conference at the A. and M. College of Texas in April 1948. The seven lectures cover phase behaviour of fluids, vapour–liquid equilibria, phase densities, water–hydrocarbon phase relations, surface tension, viscosity, and behaviour of reservoir fluids.

APPLICATIONS FOR MEMBERSHIP OR TRANSFER.

JULY 1950.

The following have applied for admission or transfer to the Institute. In accordance with the By-laws, the proposals will not be considered until the lapse of at least one month after the publication of this *Journal*, during which time any Fellow, Member, or Associate Member may communicate by letter to the Secretary, for the confidential information of the Council, any particulars he may possess respecting the qualifications or suitability of the candidate.

The object of this information is to assist the Council in grading the candidate according to the class of membership.

The names of candidates' proposers and seconders are given in parentheses.

Applications for Membership.

BEAUMONT, Frederic Norman, chief electrical engineer, Anglo-Iranian Oil Co. Ltd. (*M. A. L. Banks; R. B. Southall.*)

COWAN, Harold, assistant chemist, Messrs. W. B. Dick & Co. Ltd. (*J. Romney; W. R. Street.*)

EVANS, William Halter, deputy training manager, Anglo-Iranian Oil Co. Ltd. (*E. Thornton; R. B. Southall.*)

HELLER, Stefan Karl, on staff of Raven Oil Co. Ltd. (*E. S. Sellers; P. H. Frankel.*)

INGLE, Robert Henry James, senior commercial assistant, Shell-Mex & B.P. Ltd. (*R. J. Bressey; E. Bailey.*)

JOHNSON, Richard Michael, assistant, Distribution & Marketing, Burmah Oil Co. (P.T.) Ltd. (*P. Evans; W. E. V. Abraham.*)

JOHNSON, Stanley, marine surveyor, Messrs. Carmichael & Clarke. (*A. W. Black; W. M. Wright.*)

MALIPHANT, Frank Alan, project engineer, Anglo-Iranian Oil Co. Ltd. (*A. C. Vivian; R. E. Adlington.*)

MARSHALL, Edward Thomas, safety engineer, Kuwait Oil Co. Ltd. (*R. M. S. Owen; E. Boaden.*)

RAFFERTY, Joseph, student, National Institute of Engineering.

TAYLOR, Leonard, managing director, Tompion Oil Co. Ltd. (*G. J. Vineall; L. Mills.*)

Transfers.

CHATTING, Arthur Harold, chief electrical engineer, Messrs. E. B. Badger & Sons (G.B.) Ltd. (*R. A. King; J. T. T. Robinson.*) (*Associate Fellow to Fellow.*)

WALKER, Stanley Thomas, engineering assistant, Anglo-Iranian Oil Co. Ltd. (*R. Stansfield; L. H. Gardiner.*) (*Student to Associate Fellow.*)

NEW MEMBERS.

The following elections have been made by the Council in accordance with the By-laws.

Elections are subject to confirmation in accordance with the By-laws.

As Fellow:

GRIFFITHS, O. H.

As Members:

BEAN, J. G. LIST, W. F.

As Associate Fellows:

AFSHAR, M. V. G. FORSYTH, D. C. RIGBY, A.
DEACON, J. H. HIXON, F. E.

As Associate Members:

ANCELL, H. HEARNE, W. A. SCADDEN, L. W.
BUGBEE, H. L. HUNTER, W. J. S. STEPHINSON, P. H.
BULLICK, E. D. MOULAND, W. H. TENNANT, J. A.
CAKE, T. W. RANDS, D. N.

As Students:

GREGORY, A. S. REID, A. S. WAKELING, R. G.

As Member-Companies:

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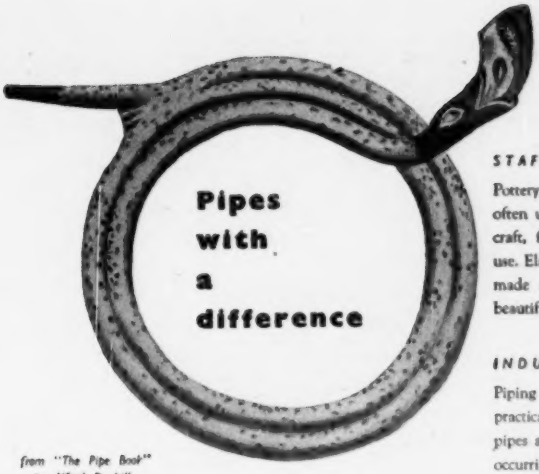

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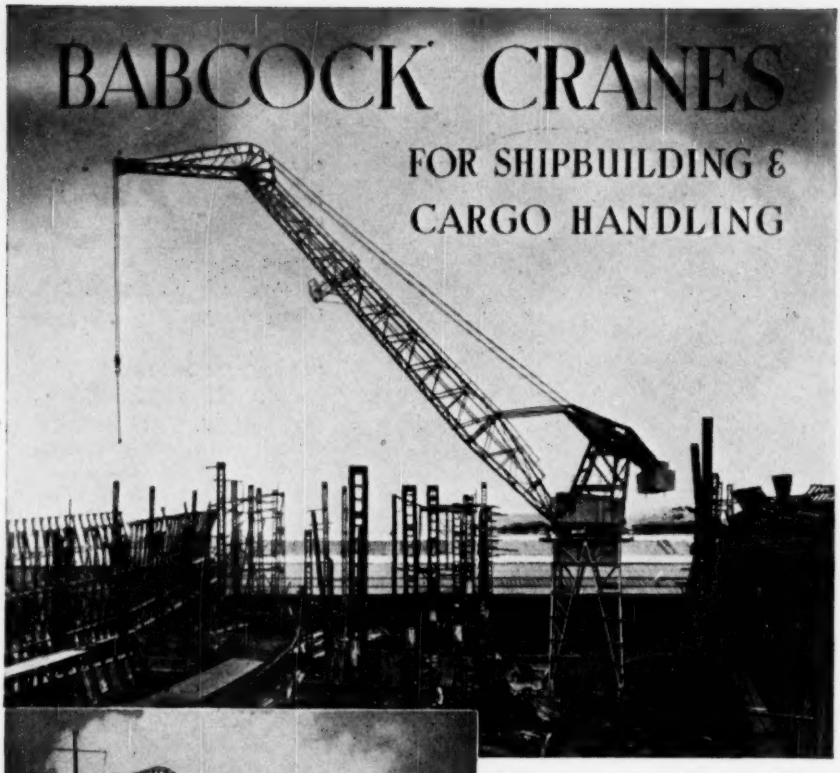

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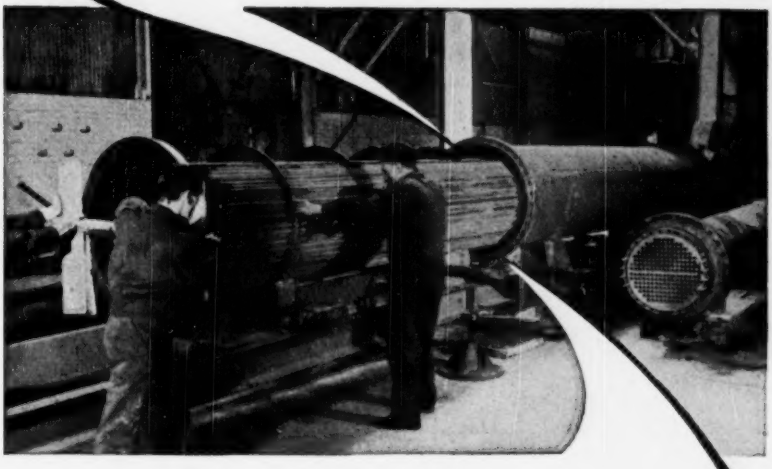

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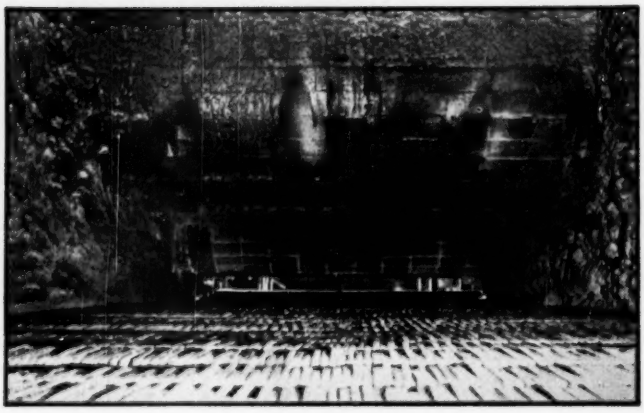

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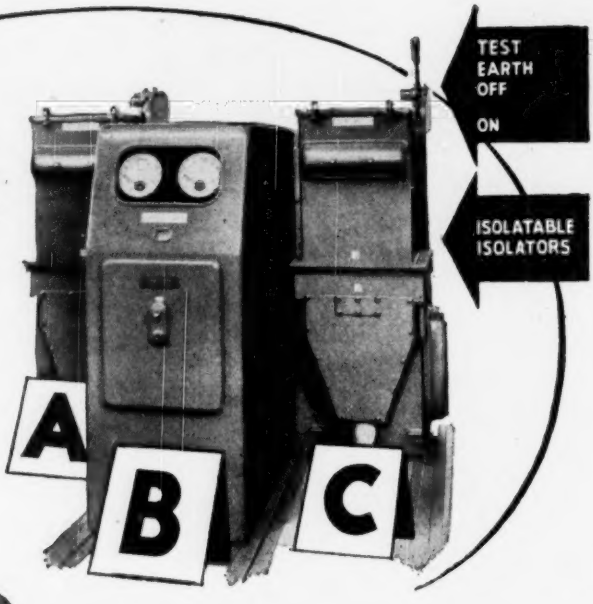

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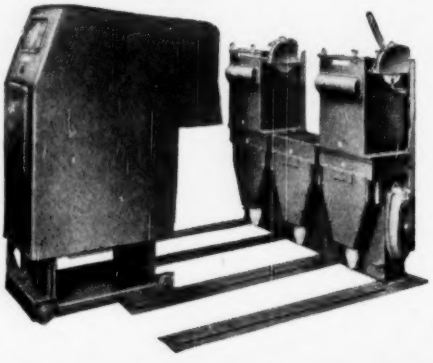

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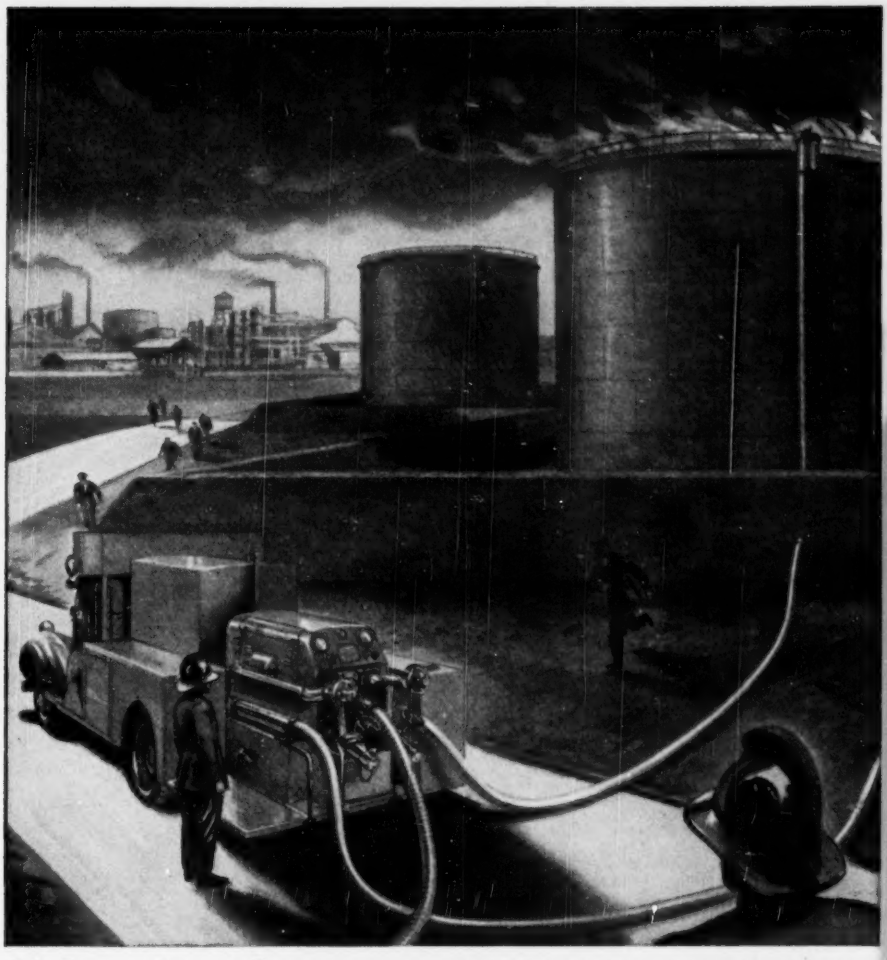

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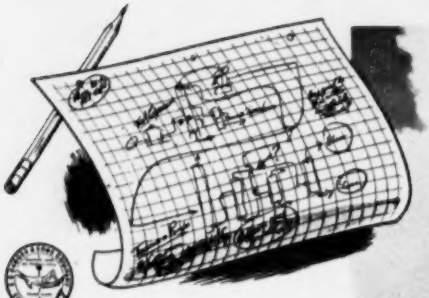

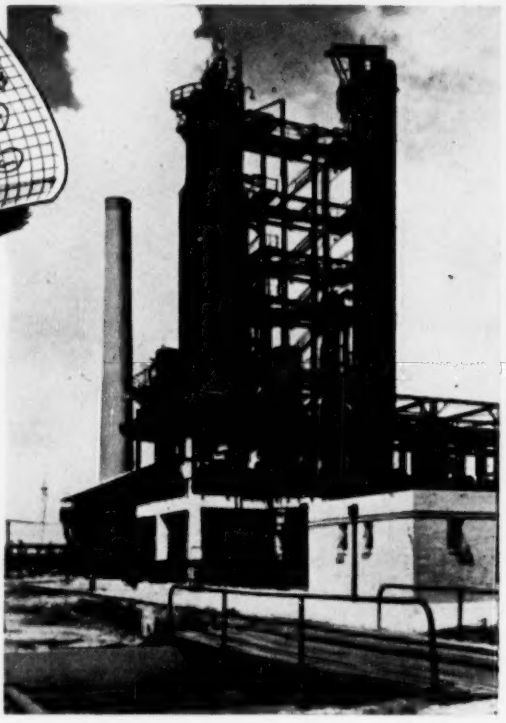

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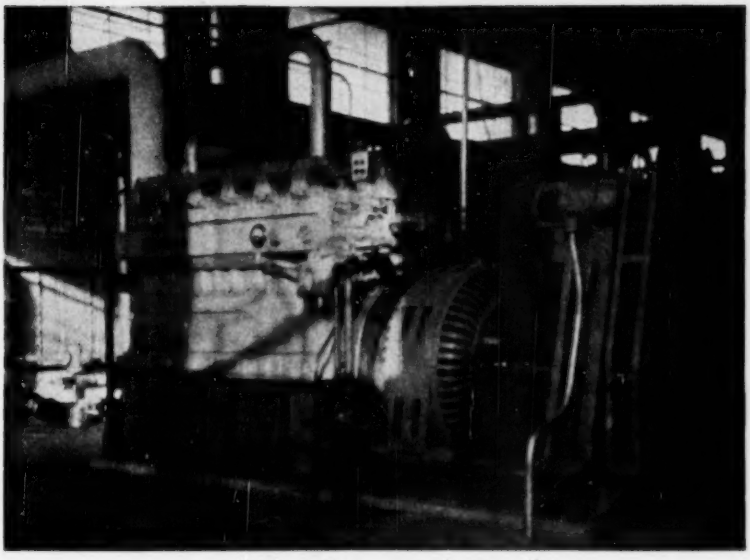

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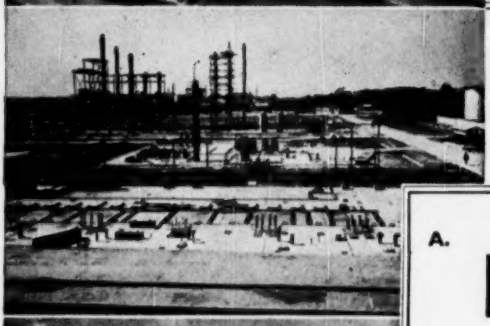

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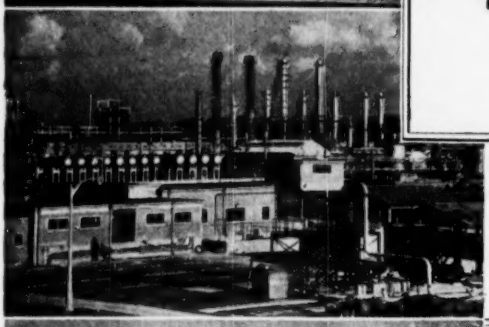

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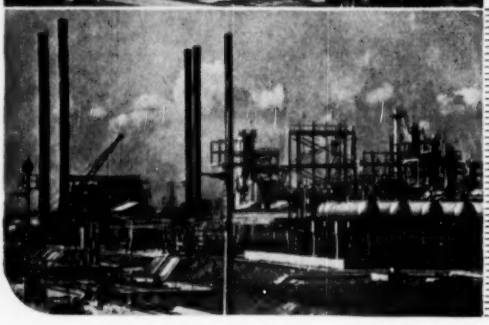

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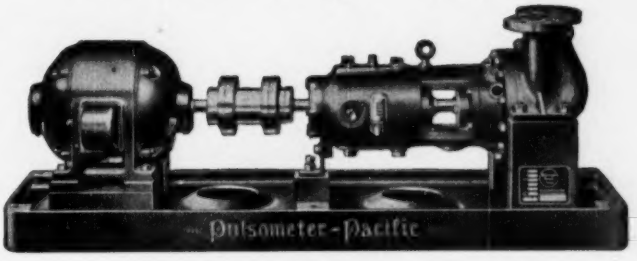

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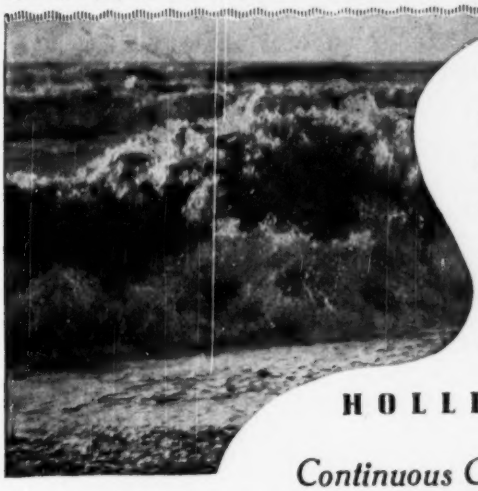

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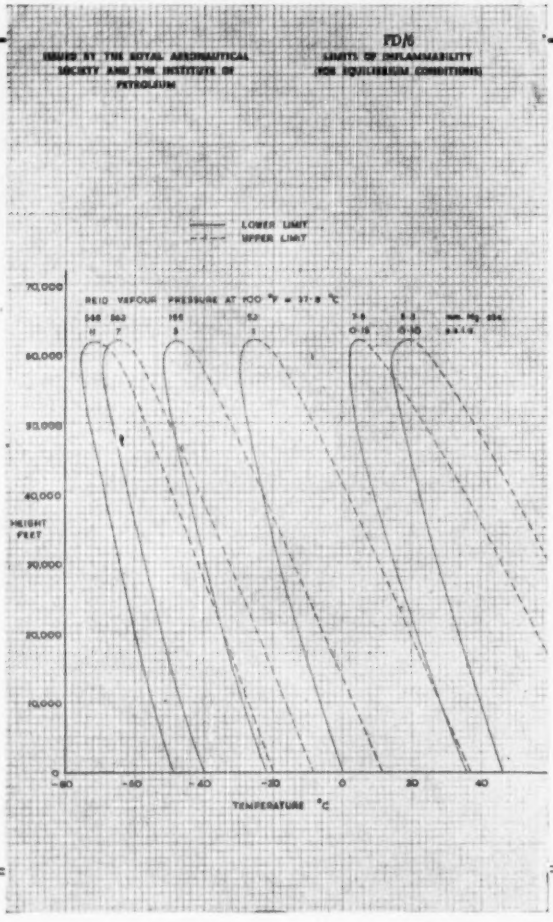

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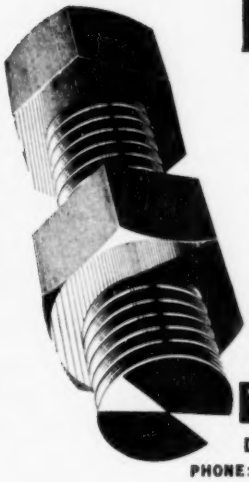

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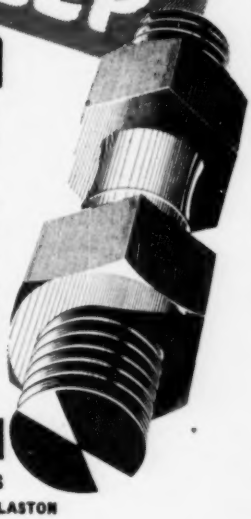

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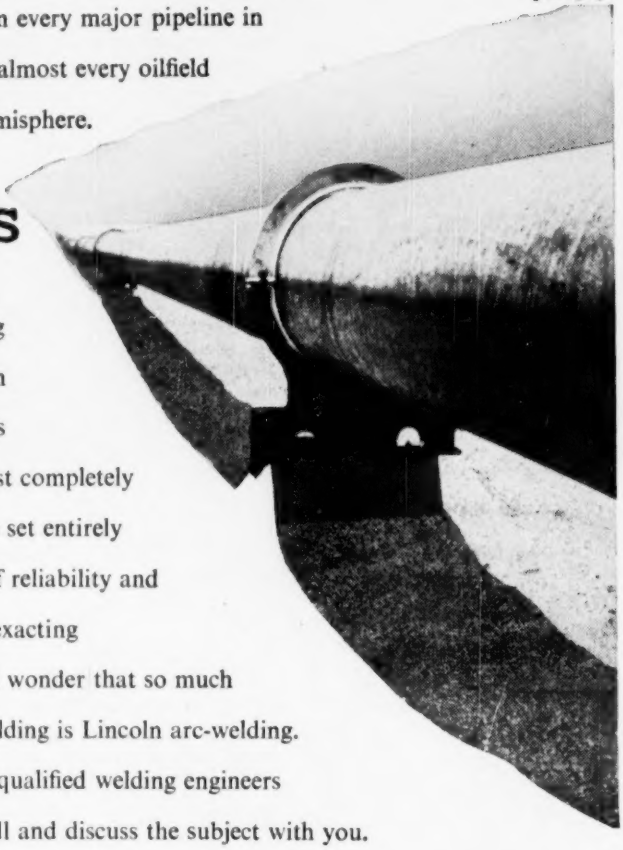

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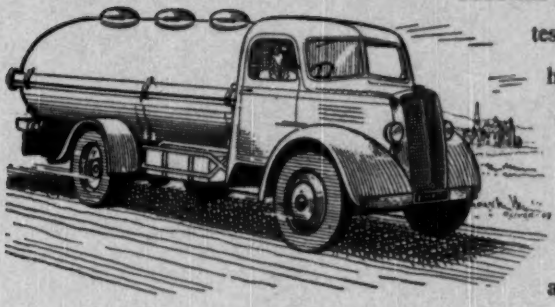

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